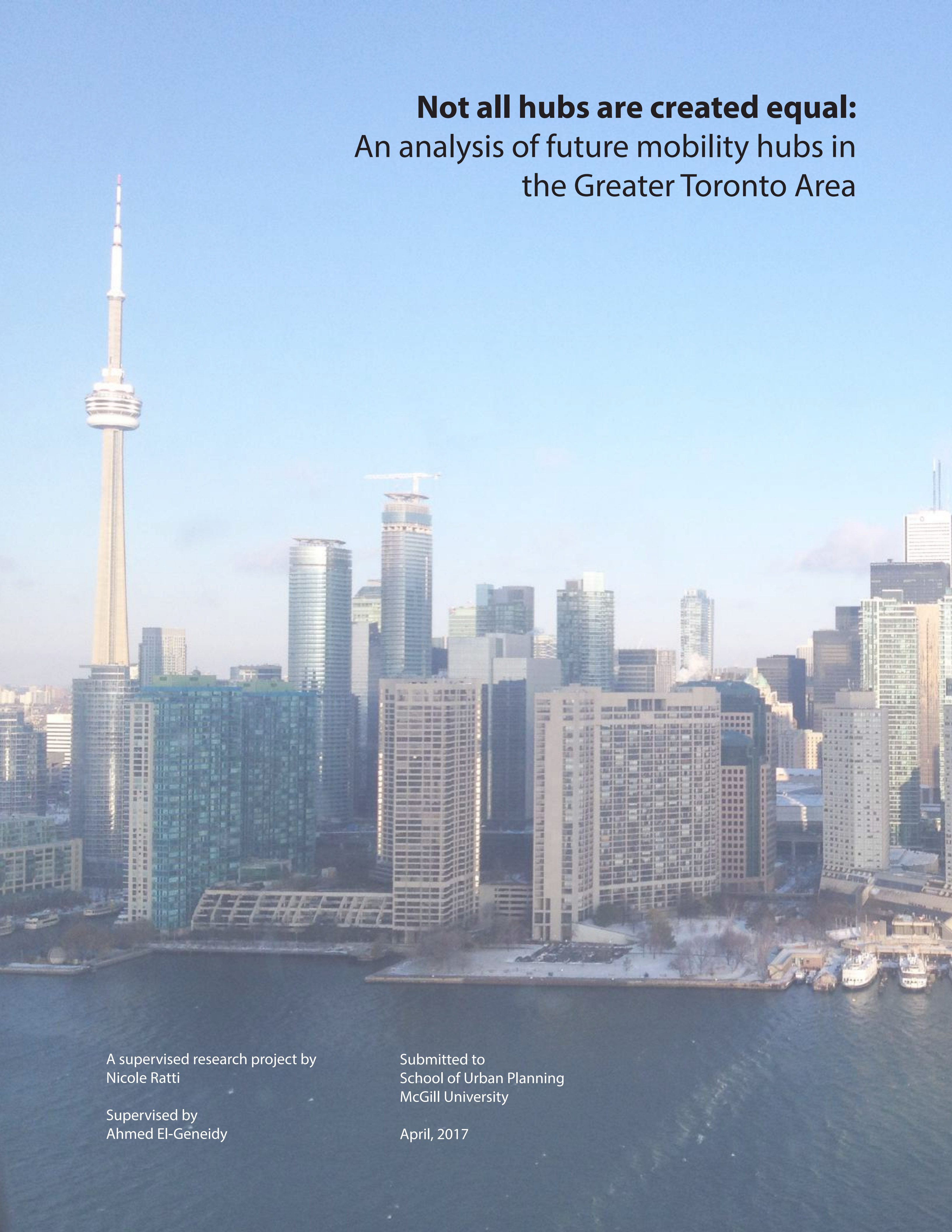
Not all hubs are created equal: An analysis of future mobility hubs in the Greater Toronto Area



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Not all hubs are created equal: An analysis of future mobility hubs in the Greater Toronto Area

Executive Summary

Prepared by: Nicole Ratti, School of Urban Planning, McGill University

The Problem:

The Greater Toronto Area is Canada's largest metropolitan region, and is home to 5.6 million people. The resulting polycentricity of the GTA has diversified commuting patterns beyond the scope of the existing public transit network, and has contributed to congestion, homogenous land use, and urban sprawl. In response, a series of mobility hubs have been created by Metrolinx, Toronto's regional transit agency, in the hopes of better connecting the GTA through public transit. The goal of this study is to isolate factors influencing transit use at trip origins and destinations, and determine how changing neighborhood characteristics can influence the success of a mobility hub, and facilitate a more connected transit network.

We select variables based on previous research, which finds that low income and recent immigrant groups rely heavily on public transit. To improve inequities in existing service, research suggests that transit agencies increase service in underserved vulnerable communities; making transit an accessible option for more commuters. Existing research also finds that high frequency transit, land use mixture, employment opportunities and high density are most conducive to public transit use.

Results:

Origin Transit Use: At home locations, proximity to subway stations and social deprivation have the largest impact on transit use. This supports existing research which advocates for service provision in low income neighborhoods, especially those with few regional transit routes, such as Scarborough or Etobicoke.

Destination Transit Use: At work locations, service frequency and proximity to a subway impact transit use significantly; favouring the urban core of Toronto. Job density also drives transit use, maximizing transit use between 1000 - 62,000 jobs/km^2 in the urban cores of Toronto, Brampton, and Mississauga; the largest employment hubs in the GTA.

Mobility Hub Success: Of the 41 mobility hubs considered, 31 require improvement as origins and/or destinations.

- All currently successful hubs are located along existing subway lines, and are often urban with mixed land use, two or more transit providers, and a mixture of residential and employment centres.
- GO transit does not provide the frequency or route choice necessary to support a hub on its own, and does not adequately address the needs of peripheral commuters.
- Peripheral hubs are less successful, and see low destination mode share due to a lack of job density, low transit availability, and homogenous land use.

Methods:

To achieve our research goals, this study is broken into two sections:

1. *Demand Modelling*
   - Derive built environment, demographic, and transit availability data at the census tract level.
   - Produce two statistical models calculating (1) origin mode share and (2) destination mode share for home-work trips.

2. *Mobility Hub Analysis*
   - Characterise a 1 km network buffer around each mobility hub, using an area-weighted average of census tracts in the buffer.
   - Calculate the origin and destination mode share of each hub, and adjust variables based on policy interventions to determine potential impact on the success of the hub.

Recommendations and Policy Relevance:

Improving the Toronto public transit network requires collaboration between Metrolinx and municipal planning agencies across the GTA. It is recommended that Metrolinx increase the presence and peak-hour frequency of service along routes connecting mobility hubs to major residential and employment destinations, and consider the extension of the Sheppard subway line to include the Don Mills-Sheppard hub. This study finds that to maximize the success of mobility hubs across the region, transit availability is not the only consideration. It lies with municipalities to address zoning, land use, and density changes. This is especially important in inner and outer suburban communities, where zoning changes to allow for high density housing, employment, and land-use mixture will facilitate a transit-friendly environment.

Table of Contents

Acknowledgements ii

Executive Summary iii

1 Introduction 1

2 Literature Review 4

2.1 Factors common to origins and destinations 5

2.2 Factors affecting transit use at the origin 6

2.3 Factors affecting transit use at the destination 7

3 Modelling Transit Demand 8

3.1 Data and Methods 9

3.1.1 Service Availability 11

3.1.2 Demographic Characteristics 12

3.1.3 Accessibility 14

3.1.4 Land Use 15

3.1.5 Measuring Transit Share 16

3.2 Results and Discussion **18**

3.2.1 Origin Demand Model 18

3.2.2 Destination Demand Model 22

4 Mobility Hub Analysis **27**

4.1 Data and Methods 30

4.2 Results 31

4.2.1 Mobility Hub Performance 40

4.3 Case Study Analysis 36

5 Conclusion **46**

6 References **49**

List of Figures

Figure 3.1: Population density at the census tract level, people/km^2
Figure 3.2: Job accessibility by transit across the Greater Toronto Area
Figure 3.3: Existing origin and destination mode share, transit and car
Figure 3.4: Origin Mode Share and Population Density
Figure 3.5: Job Accessibility – GTA Census Tracts
Figure 3.6: Transit share and job density at trip destinations (census tract level)
Figure 3.7: Car and transit mode share in relation to average Walk Score of the destination

Figure 4.1: Context Map of GTA Mobility Hubs
Figure 4.2: Highest and lowest performing mobility hubs (by mode share)
Figure 4.3: Final recommendations to improve transit demand at mobility hub
Figure 4.4: Mississauga City Centre Mobility Hub Land Use Profile
Figure 4.5: Yonge Eglinton Mobility Hub Land Use Profile
Figure 4.6: Seaton Mobility Hub Land Use Profile
Figure 4.7: St George Mobility Hub Land Use Profile

List of Tables

Table 3.1: Summary Statistics of Tested Variables
Table 3.2: Social Deprivation Factor Analysis
Table 3.3: Model 1 – Transit Mode Share (Origin)
Table 3.4: Model 2 – Transit Mode Share (Destination)

Table 4.1: Mobility Hub Performance and Suggestions for Improvement
Table 4.2: Explanation of case study rankings
Table 4.3: Mississauga City Centre Characteristics
Table 4.4: Yonge Eglinton Hub Characteristics
Table 4.5: Seaton Hub Characteristics
Table 4.6: St George Hub Characteristics

1 INTRODUCTION

Introduction

Although early public transportation and heavy rail monopolized commuting mode share in the early 1900s, the automobile era and decentralization of homes and jobs have instilled car-dependency on North American society. As a result, major cities experience record high peak congestion, increased average commute times, and diminished transit use (Garrison & Levinson, 2005).

In response to productivity loss caused by congestion, planning authorities are refocusing policies to induce a modal shift towards active transport; such as cycling, walking and the use of public transit. Though large-scale master plans and the overhaul of existing transit networks may improve transit mode share in many cities, it is also important to consider solutions that will get the most bang for the government's buck. Transit service often favours urban and peak-hour commuters; leaving suburban communities and peripheral commuters with few alternatives to the car. Supported by a slate of literature advocating for well connected and intermodal transit systems, cities often rely on mobility hubs in order to move people efficiently and benefit the most people with offered services and local opportunities (Gutiérrez, Cardozo, & García-Palomares, 2011; Mishra et al., 2015; Taylor, Miller, Fink, & Iseki, 2009). More than transit stops, these hubs are expected to support diverse transit modes, and serve as origins, destinations, and transfer points; connecting people and places seamlessly (Metrolinx, 2008a).

The inspiration for this SRP is to determine how changing built environment and transit service characteristics can influence the success of a proposed mobility hub, and facilitate a more connected transit network, serving the needs of daily commuters. While motivating factors of transit use have been extensively studied, there is little academic work examining the characteristics of a successful mobility hub. This study contributes to this gap in the literature, developing a series of success criteria for mobility hubs within the context of the Greater Toronto Area, Canada's largest metropolitan region. While most applicable to Metrolinx, the Regional Planning Agency in the Greater Toronto Area, the policy-driven recommendations used in this study can be of benefit to other planning agencies looking to create, or improve mobility hubs.

As Canada's largest Census Metropolitan Area, the Greater Toronto Area is currently home to 5.6 million people, spread across five regional municipalities. To accommodate the needs of a continually growing population, Metrolinx, an agency of the Ministry of Transportation Ontario (MTO), introduced the Big Move Plan in 2008. Proposing a 25 year, 50-billion-dollar integrated transit plan for the Greater Toronto and Hamilton Area (GTHA), the Big Move is one of the largest transit expansion programs in North America. To form the foundations for a well-connected transit network, Metrolinx revealed the locations of 51 Mobility Hubs across the GTHA (Metrolinx, 2015). Through a recent overhaul of the Mobility Hub Profiles and guidelines in 2015, there are currently two overarching typologies of mobility hubs in Toronto; gateway and anchor hubs. Gateway hubs are major transit stations where two or more regional transit lines will connect by 2031. With a focus on intermodality and density, Gateway hubs are also set to exceed a moderate threshold of 10,000 combined residents and jobs within an 800m radius (Metrolinx, 2008a, 2015). Anchor Hubs, conversely, contain current or planned major regional destinations such as major institutions, employment centres, town centres or regional shopping centres, and they have significant potential to attract and accommodate new growth and development (Metrolinx, 2008a).

To determine the success of a mobility hub, the first goal of this SRP is to understand existing literature outlining factors affecting transit demand. Following this, we seek to apply the findings of previous research to better understand demand for public transit. While existing literature often considers demand holistically, we separate outbound (origin) and inbound (destination) demand for transit at the census tract level. Using demographic, built environment, and transit service characteristics informed by existing literature, we derive two statistical models which separately explain origin and destination mode share across the GTA. We expect different results between the models, and believe that the use of transit at home or at work are informed by different factors; all of which must be considered by planning agencies when improving transit infrastructure.

Having developed a method for predicting origin and destination transit demand, the final phase of this project applies these models to all mobility hubs across the GTA. We predict the existing origin and destination mode share of all hubs, and categorize them based on areas of suggested improvement. Using a slate of policy recommendations, we alter characteristics about each hub while holding all other variables constant, and establish best-case scenarios for the improvement of each hub. The recommended interventions are customized to each hub based on existing transit use, population and built environment characteristics, level of current development, transit availability, and location within the GTA. To provide additional detail on the relative success levels of mobility hubs, we present four case studies selected on the basis of their mode share, and balance as origins and destinations. For each case study, we propose detailed policy interventions to improve their future performance. Findings from this study can isolate policies for improving transit demand both within and outside of the GTA, as the interventions used are universally applicable to many major cities.

TTC Subway, Toronto, TRAM

2 REVIEW OF EXISTING LITERATURE

2 Literature Review

Variables associated with transit mode share can be divided into three categories; variables pertaining to personal characteristics and socioeconomic status, those relevant to the local built environment, and those specific to the quality and availability of local and regional public transit service. Travel behaviour is multifaceted, and while traditional public transit investment focuses on the trip itself, this study adopts the "whole journey" philosophy, from origin to destination (Suzuki, Cervero, & Iuchi, 2013). In this study, we focus on home-work trips, thereby isolating factors relevant to transit use at origin home locations, and destination work locations. With this in mind, the following section will outline the factors influencing transit use in precedent literature, with particular focus on what motivates transit use at trip origins, and destinations.

2.1 Factors common to origins and destinations:

Although home and work locations are often different, several factors emerge from existing literature as relevant to transit use at either trip origins or destinations. Transit use relies heavily on transit availability, making proximity to transit a determining factor of transit use (Suzuki et al., 2013). A study in Chicago found that a distance of less than one mile to a rail station at both ends of a trip is most likely to incentivize transit use (Lindsey, Schofer, Durango-Cohen, & Gray, 2010). This suggests that while proximity to transit is important, the ability to walk to transit further incentivizes its use (Murray & Wu, 2003). While studies find that most commuters are willing to walk up to 800 m (0.5 mi) to access a rail station, newer research suggests this value could be even higher (El-Geneidy, Grimsrud, Wasfi, Tétreault, & Surprenant-Legault, 2014; Murray & Wu, 2003), therefore living or working in walkable proximity to a rail station is a key factor in transit use.

While proximity to transit is linked to ridership, not all stations can be considered equal, and therefore location is a key factor in transit use. As most trips on rail transit take place in dense, urban rail networks, a downtown or urban rail hub is likely to cultivate ridership from a smaller catchment area than sparse suburban hubs (Kuby, Barranda, & Upchurch, 2004). Additionally, the type of station (terminal, intermodal, intermediate, or interchange) is relevant to the ridership flows of a rail station. Terminal stations tend to have larger catchment areas and high ridership from otherwise unserved neighborhoods nearby, while intermodal stations tend to see high ridership from connecting modes of transit (Gutiérrez et al., 2011). Interchange stations experience higher ridership than intermediate stations, and therefore station characteristics must be carefully considered in conjunction with one's proximity to these stations. Convenience and efficiency drive the commuting patterns among many households. Taylor et al. (2009) explored absolute and relative transit use in 265 urban areas throughout the United States. Using regression models to account for transit supply and usage, this study finds that service frequency is a significant factor in transit use, and accounts for 26% of the variation in ridership among all urban areas in the United States. Further to this, it is believed that the speed, capacity, and frequency of transit routes directly impact the connectivity of the network and relative efficiency of a transit line, increasing its utility for potential users (Mishra et al., 2015).

2.2 Factors affecting transit use at the origin:

Built environment characteristics do not paint the whole picture of transit use. As the name implies, mode choice is an individual choice, and therefore the needs and characteristics of residents using transit must be considered. The decision to use public transit is driven in part by socioeconomic status, and financial stability. While socioeconomic status is multifaceted, income and race emerge at the forefront of relevant literature. Garrett and Taylor's (2000) study of public transit equity found that low-income and minority groups are more often captive riders of public transit systems (Garrett & Taylor, 2000), as the person can not afford to purchase a car, and is dependent on public transit. Mode choice is not the only barrier faced by socially disadvantaged groups. Commuting distance between home and work, also referred to as spatial mismatch, is often much larger for low-income and migrant groups as suburbanizing employment has left many vulnerable groups concentrated near the city centre, with little access to their places of work (Stoll, 2006). Many cities in Canada, including Toronto, mirror the urban-centric public transit networks found in Stoll's U.S-based research, where low income groups live around the downtown, but low income jobs are located further from the city centre; and often in the suburbs (Legrain, Buliung, & El-Geneidy, 2015; Stoll, 2006).

In order to fully understand the impact of socioeconomic status on transit use, studies have shifted towards social indicators; combining many demographic factors (Foth, Manaugh, & El-Geneidy, 2013; Legrain et al., 2015). Foth et al. (2013) work in categorize social disadvantage in Toronto is highly relevant to this study. They combine z-scores of median household income, unemployment, recent immigrants and the percentage of households that spend more than 30 percent of income on housing to summarize socioeconomic status in Toronto. These indicators, when combined, produce a "social deprivation indicator" which can be easily split into a series of deciles for spatial analysis at the census tract level. This indicator supports claims made in the literature that financial barriers caused by low income, recent immigration, and unemployment lead to higher transit use for trips originating in socially deprived neighborhoods (Foth et al., 2013; Taylor et al., 2009).

While socially vulnerable groups face unique barriers to mobility, all home-work commuters travel with the same goal; to reach their place of work. In order for work trips to take place by transit, jobs must be accessible by transit (Foth et al., 2013; Gutiérrez et al., 2011). Foth et al. (2013) measure job accessibility by transit using a gravity-based measure, which weighs jobs closer to the origin as more important. Findings from this study suggest that job accessibility by transit in Toronto is highest in the downtown core, and along existing subway lines. This suggests that suburban and rural neighborhood residents are less likely to use transit for work commutes as they are served by fewer transit lines, and can access fewer jobs.

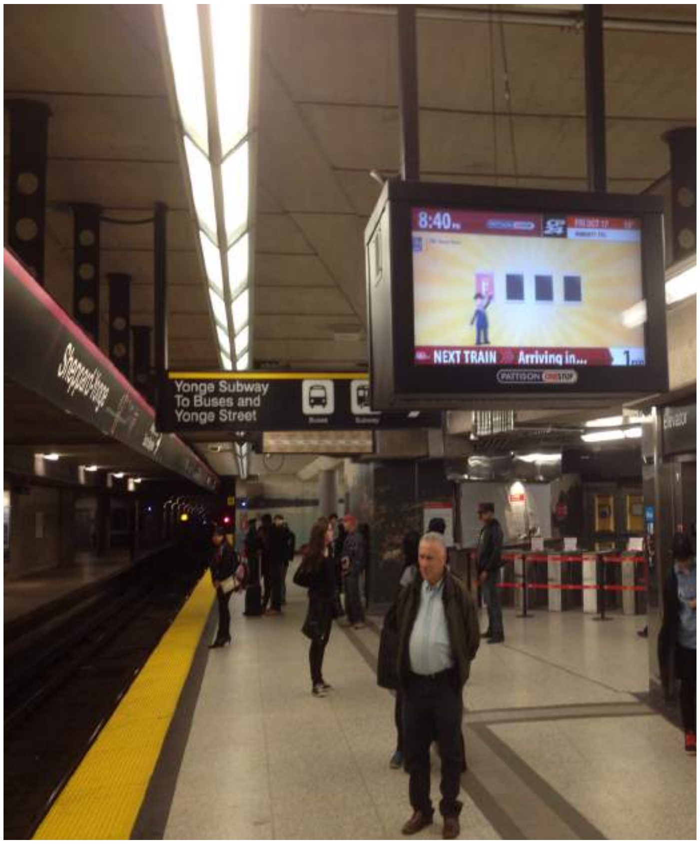
Population density is widely viewed as being positively associated with transit use, and a higher likelihood of walking to transit, regardless of neighborhood economic status (Cervero & Kockelman, 1997; Chen & Paaswell, 2008). High density is associated with concentrated work and non-work activities, which are necessary for trip chaining, and the provision of a competitive transit service (Chen & Paaswell, 2008; Giuliano, 2003). Despite its support in the literature, Badoe and Miller (2000) and Crane and Crepeau (1998) suggest that the perceived relationship between the built environment and transit use may be erroneous, driven instead by confounding variables such as accessibility, travel cost, and residential self selection (Chen & Paaswell, 2008). Although these discrepancies in the literature are present, many studies continue to use density in models predicting mode share, while also controlling for confounding variables (Murray & Wu, 2003). At the end of the day, the more people living in close proximity to transit, the more likely the service will be used (Chan & Miranda-Moreno, 2013; Gutiérrez et al., 2011; Murray & Wu, 2003).

2.3 Factors affecting transit use at the destination:

Adding to the importance of population density, existing literature finds that job density is a strong predictor of transit use, even when controlling for confounding variables at the destination (Chen, Foth). In a study conducted by Cervero and Wu (1998), it is determined that an area's job density has an impact on the mode share of trips used to reach it. Their findings suggest that suburban and exurban employment hubs with low job density averaged higher car mode share in the San Fransisco Bay Area, and see negligible transit use in comparison to high-density urban employment. In many cities, the suburbanization of employment has led to polycentric employment, and a series of lower density hubs where the average commute distance is increasing. As a result, many families are forced to move even further out of the city to purchase a home (Cervero & Wu, 1998; Legrain et al., 2015). As such, high job density is still most likely to exist in the CBD (central business district), where numerous transit opportunities exist. Transit may not sufficiently accommodate peripheral commutes to suburban employment centres, as their density is not high enough to support transit. When considering the whole journey from origin to destination, job density at the destination is thought to have more impact on transit use than population density at the origin (Chen & Paaswell, 2008; Foth et al., 2013).

The following section will apply the factors found in precedent literature, as we develop two statistical models which collectively explain transit mode share at the origin and destination within the Greater Toronto Area.

High frequency Toronto subway, TRAM



3 MODELLING TRANSIT DEMAND

3.1 Data and Methods

To obtain a better understanding of travel demand, this study uses a series of variables derived from previous literature to assess transit demand both to and from each census tract in the GTA. In this study, origin transit share refers to the percentage of home-work trips originating within a given census tract using public transit as their primary mode. Conversely, destination transit share refers to the mode share of home-work trips terminating within a given census tract (CT). The assessment of both origin and destination transit mode share at the census tract level provides additional nuance that is currently lacking in existing literature. In this study, two linear regressions were used to predict transit demand. While some variables are present in both models, many factors are specific to either trip origin or destination, since travel preferences into and out of a neighborhood can vary heavily. Table 3.1 summarizes the variables tested in these models, followed by a discussion of each variable considered, and its expected behaviour within each model.

Bloor St. corridor, Toronto, TRAM

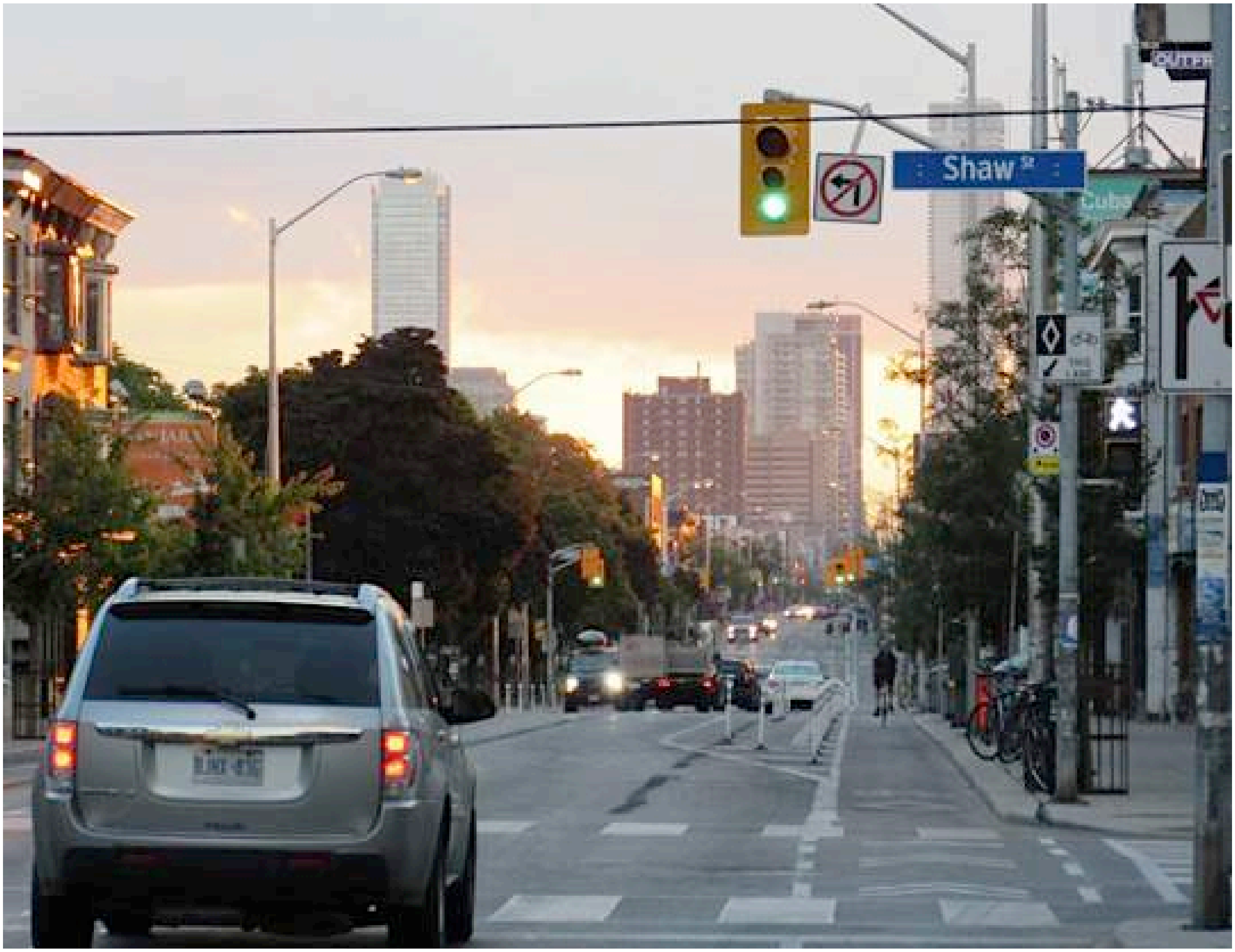


Table 3.1: Summary Statistics of Tested Variables

Independent Variables						
Variable	**Description**	**Min**	**Max**	**Mean**	**Median**	**Std. Dev.**
Income	Median after-tax household income (Canadian Census, 2011) in Canadian Dollars	23081	163944	66791.56	64977.50	20552.077
Recent Immigrants	Percent of residents who have immigrated within the last 5 years	0.00	5.11	6.14	5.00	5.11
Unemployment Rate	Percent of working-age, non-student resident who are unemployed	0	31.5	9.11	8.60	3.91
Housing Affordability	Percentage of residents spending over 30% of income on housing	3.0	33.0	11.1	10.0	4.94
Household Size	Average number of persons living within a single household	2.2	3.8	3.03	3.00	0.26
Population Density	Population (thousands) per km2	0.02	60.9	5.08	3.56	5.74
Population Density Squared	Square of population density	0.0004	3708.75	58.82	12.65	228.88
Job Accessibility	Gravity-based accessibility to jobs using public transit system	0.17	224.29	103.98	107.55	50.26
Distance to Highway	Network distance from centroid to nearest highway on ramp (km)	0.01	38.83	3.57	2.78	3.38
Worker Accessibility	Gravity based accessibility from a designated point to potential workers nearby.	0.34	461.33	86.77	81.80	51.49
Job Density	Jobs (thousands) per km2	0.00	88.83	1.69	0.53	5.63
Job Density Squared	Square of job density	0.00	7890.68	34.54	0.28	358.61
Service Frequency	Average bus/train frequency at each stop within a census tract	0.00	55.0	10.81	8.08	8.43
Distance to GO Station	Distance (km) to the nearest GO rail station.	0.30	41.52	4.64	3.69	4.11
Walk Score	Walk Score of the CT centroid, or nearest on-street location.	0.00	100.00	60.89	63.00	23.91
Subway (Dummy)	Dummy variable equal to 1 if centroid of census tract is within 1 km of subway station	0.00	1.00	9% in 1km radius	--	--
Dependent Variables						
Variable	**Description**	**Min**	**Max**	**Mean**	**Median**	**Std. Dev.**
Transit Mode Share (Origin)	Existing public transit home-work mode share originating from the identified census tract.	0.00	73.37	22.29	18.59	14.64
Transit Mode Share (Destination)	Existing public transit home-work mode share terminating in the identified census tract.	0.00	60.15	15.96	12.86	13.61

3.1.1 Service Availability:

It is believed that availability of service affects transit use at both the origin and destination (Chakour & Eluru, 2013; Lindsey et al., 2010). Several variables are used to demonstrate transit service availability across the Greater Toronto Area. These include distance to commuter train stations, regional bus transit, subway stations, and service frequency. To obtain the proximity to subway and train stations, we run a closest facility analysis in GIS to measure network distance between the centroid of each census tract, and its nearest GO station. As GO is the only regional transit provider in the GTA, it is expected that closeness to a GO rail station or regional bus terminal will increase transit share as accessibility to jobs by transit increases along a well-connected transit network. The location of each GO station is obtained from General Transit Feed Specification (GTFS) data (TransitFeeds, 2017), and we include only rail stations and bus terminals (n=200), which reflect the regional scale of the GO transit system.

Although GO is the sole regional transit provider in the GTA, it is not the only rail transit provider. The Toronto Transit Commission, the service provider for the City of Toronto proper, operates a well-used subway system, composed of three subway lines, and one above ground LRT. As existing literature suggests that the ability to walk to a rail station incentivizes transit use (Lindsey et al., 2010; Moniruzzaman & Páez, 2012; Murray & Wu, 2003), we generate a dummy variable to measure this threshold of walkable access to the subway. This variable differs from the continuous distance measured to GO stations, as most GO stations in the GTA are suburban, and have a large service area caused by low housing density, and car dependence. These stations may therefore attract riders from a larger distance, as ample parking at stations may incentivize driving to transit. The Toronto subway system, however, is mainly urban, and stations are densely packed along each line. Therefore, a dummy variable was used if the census tract centroid is within a 1 km network distance from a subway station (El-Geneidy et al., 2014). It is expected that census tracts within 1 km of one or more subway stations will see an increased transit mode share, due in part to the dense, urban nature of the Toronto subway, and the perceived convenience of walking to transit (Morency, Trepanier, & Demers, 2011).

The final variable associated with transit availability is service frequency, which alludes to the quality and convenience of local transit (Taylor et al., 2009). We use GTFS stop times data for all nine transit providers in the GTA, and determine the number of times a bus or train arrives at each bus or rail stop during the morning peak (6 am to 9 am) (TransitFeeds, 2017). This value is then divided by three to obtain hourly average frequency. For this data to be useful in statistical models, it must be aggregated at the census tract level. To do this, a spatial intersect is performed in GIS, which summarizes the average per-stop transit frequency for each census tract in the GTA. We express frequency in vehicles per hour, and therefore it is expected that a greater frequency will induce an increase in transit use as the convenience and number of commuting options increase. Overall, it is known that service availability directly affects job accessibility and the ease of completing first and last mile trips (Lachapelle, Frank, Saelens, Sallis, & Conway, 2011). It is therefore expected that the service availability indicators considered in this study will positively impact transit use throughout the GTA.

3.1.2 Demographic Characteristics:

In addition to service characteristics, it is well established in the literature that socioeconomic status; particularly social deprivation and vulnerability, limits travel mode options based on affordability, and availability within socially deprived areas (Foth et al., 2013; Pasha, Rifaat, Tay, & De, 2016; Taylor et al., 2009). Using data obtained from the 2011 Census, five demographic variables were considered in this study, which are directly relevant to the affordability and practicality issues of different transit modes (Statistics Canada, 2011b). We therefore consider the following variables:

- Median Household Income
- Percentage of the labour force that is unemployed
- Percentage of residents that have immigrated in the last five years
- Percentage of households spending more than 30% of their income on housing
- Household size

In precedent literature, many of the above variables have been combined in a deprivation indicator using combined z-scores (Foth et al., 2013; Legrain et al., 2015). While this method is highly summative and provides a general picture of social vulnerability, varied correlations between many of these variables suggest that this level of aggregation may not be necessary, and may not capture nuances in the data sufficiently. Table 3.2 demonstrates the results of a factor analysis, which separates these variables into two distinct factors based on Eigenvalues greater than 1. The component rotation used produces two factors. The first concentrates on household income and the financial burden of housing and household size, while the latter isolates unemployment and the disproportionately high barriers to employment faced by recent immigrants (Pasha et al., 2016).

Due to the daunting expense of car ownership, transit use by low income, immigrant, or unemployed groups is disproportionately high in many cities (Foth et al., 2013; Ong & Miller, 2005). We therefore expect that an increase in the Financial Barriers factor, which indicates a high-income neighborhood with high average family size, will exhibit lower transit use, as these communities tend to opt for the perceived convenience of the car. This is especially true in high income suburban communities, where alternative modes to the car are limited in the GTA. Conversely, with a concentration of recent immigrants and unemployment (employment status factor), we

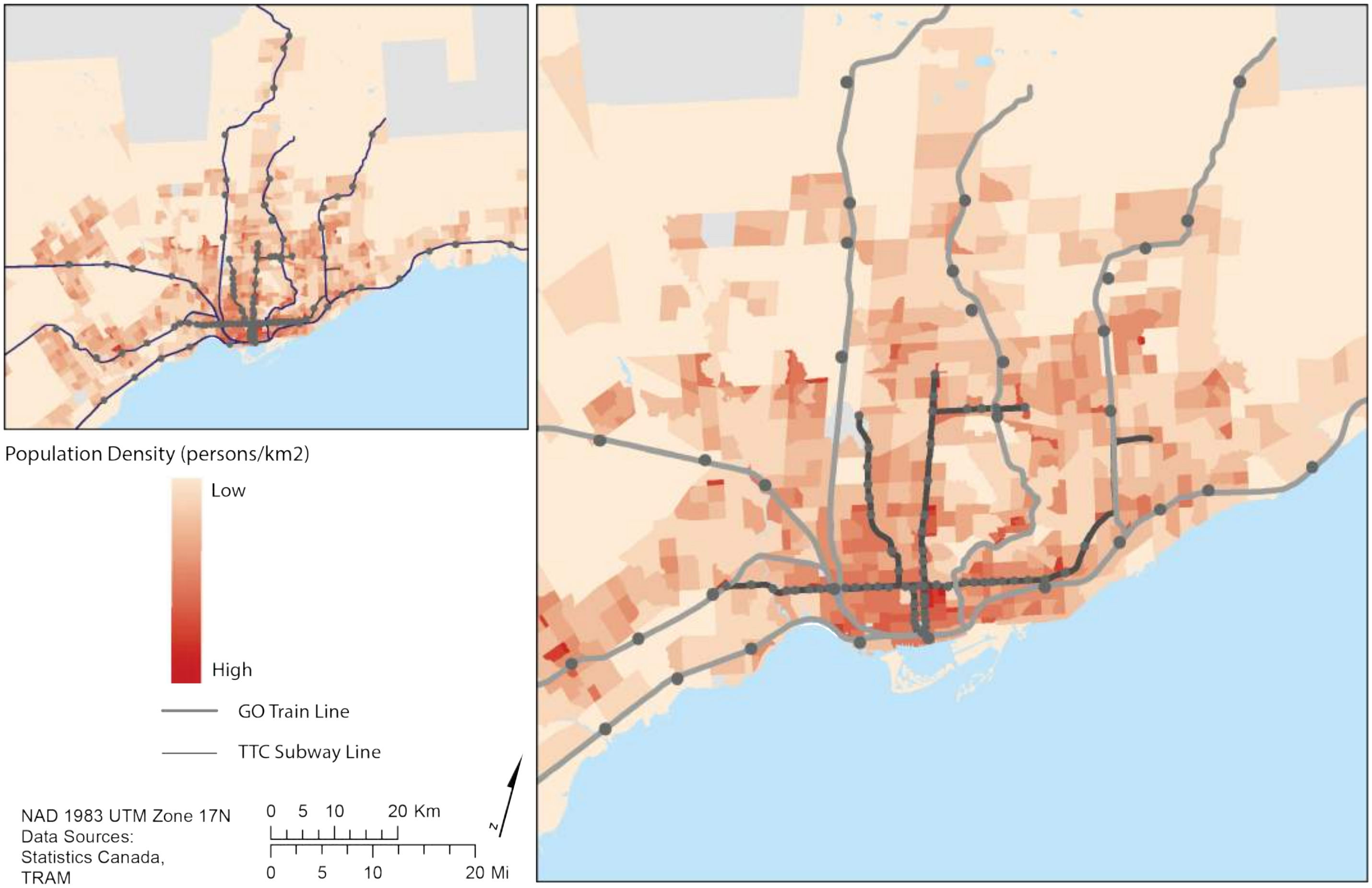
Table 3.2: Social Deprivation Factor Analysis

	Factor	
	Financial Barriers	Employment Status
Income	**.728**	-.515
Recent Immigrants	-.217	**.832**
Unemployment	.046	**.869**
Housing Affordability	**-.880**	.289
Household Size	**.915**	.241

expect an increase in transit use, as these marginal groups often lean on public transit in response to a unique set of financial barriers (Taylor et al., 2009).

Beyond the characteristics of the local population, literature suggests that density drives transit demand (Cervero & Kockelman, 1997; Chen & Paaswell, 2008). We calculate population density at the census tract level using population counts from the 2011 Canadian Census, which is then divided by the land area of the census tract (Statistics Canada, 2011b). Figure 3.1 shows that census tracts in the GTA can be as dense as 60,000 people/km2; significantly higher than the Toronto CMA average of 900 persons/km2 , which is heavily skewed by low density neighborhoods at the peripheries of the GTA (Statistics Canada, 2011c).

Figure 3.1: Population density at the census tract level, people/km2



To ensure the accuracy of these findings, a detailed analysis was performed to verify the approximate density of the twenty densest census tracts in the GTA. To do this, we use MLS real estate listings and Google Earth imaging to determine the approximate capacity of residential towers in high density census tracts. The results determine that census tracts with densities over 40,000 people/km^2 are usually caused by a small census tract of 1-2 city blocks, populated by several residential towers of 30+ storeys (Google Earth, 2017; Realtor MLS Listings, 2017). We determine that above average population densities are plausible in these cases, and therefore the results shown in figure 3.1 are well supported. As population density informs the number of potential users in proximity to transit, we expect population density and transit use are positively correlated (Chan & Miranda-Moreno, 2013; Gutiérrez et al., 2011). We would therefore predict highest transit use in the downtown core, with progressive decrease in transit use outward from the CBD.

3.1.3 Accessibility:

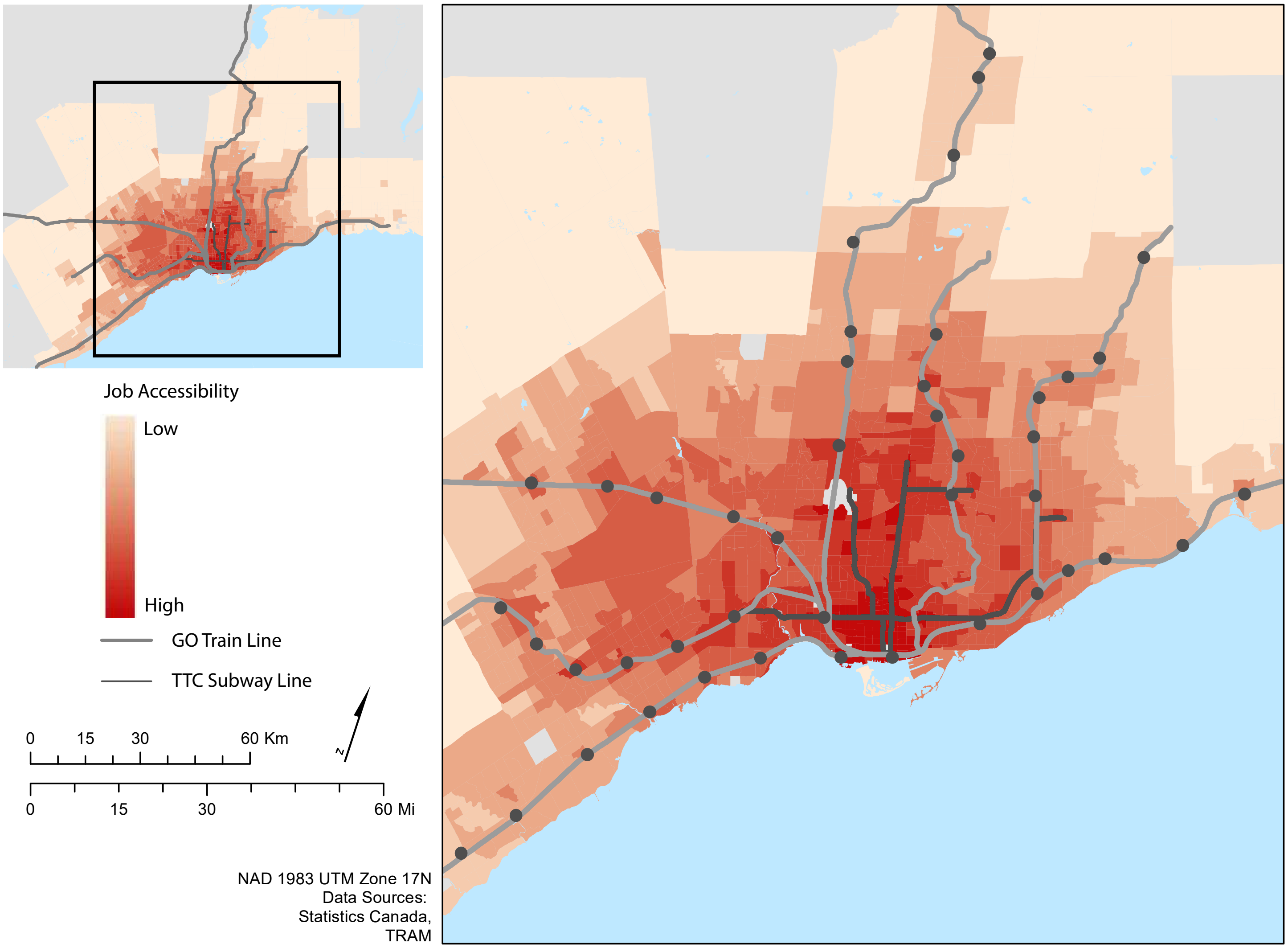
The final consideration in transit share is the built environment, including the prevalence of home and work locations, which foster commuting trips. To evaluate the number of possible destinations necessary to stimulate travel, we use job and worker accessibility. For the purposes of this study, accessibility is the number of opportunities reachable using the public transit network (Moniruzzaman & Páez, 2012). We use gravity-based accessibility, which decreases the weight and relative importance of opportunities located further from the origin (Owen & Levinson, 2015). This study primarily considers home-work trips, and therefore we first measure accessibility to all job types using the following gravity-based measure (Hansen, 1959):

$$A_i^{\text{pub}} = \sum_{j=1}^{n} D_{e^{-\beta cij}}$$

where job accessibility A is the accessibility at point i within region j, measured in travel time (Cij) between census tracts i and j. Data for travel time using transit between all census tracts is derived from GTFS data (TransitFeeds, 2017), and we derive the number of jobs in each census tract from census commuter flows data (Statistics Canada, 2011a). The use of transit to complete work commute trips relies on the ability to access jobs using the transit network. Figure 3.2 shows that job accessibility is currently lowest in the outer suburbs of the GTA, and increases quickly with proximity to the central business district. We therefore expect that higher job accessibility by transit will result in increased transit use, especially in proximity to the downtown core and along transit corridors where accessibility to jobs by transit is highest.

Broadview Station, Toronto, TRAM

Figure 3.2: Job accessibility by transit across the Greater Toronto Area



While job accessibility by transit evaluates accessible work destinations, and how many commuters can feasibly use transit to access their jobs, it does not take into consideration the local demand for transit, measured in local workers seeking to access their job. To satisfy this gap in data, we also calculate accessibility to workers, or the number of workers that can access a given destination using public transit. This value is calculated similarly to job accessibility, and weighs accessible workers by distance from the destination in question. A higher worker accessibility value suggests a high potential demand for transit; therefore, we expect this value to be positively correlated to transit use. However, while transit demand for work commutes may exist, this neighborhood must also supply a proportional number of job opportunities, providing commuters with a transit-accessible destination.

3.1.4 Land Use:

To measure these opportunities in a standardized and comparable way, we calculate job density. We obtain the number of jobs in each census tract using 2011 Census commuter flow data, and calculate the total number of work-trips terminating in each census tract (Statistics Canada, 2011a). Similar to how population density was calculated previously, we divide the number of jobs by the land area of the CT to standardize the results across the region. Job density is highly variable in the GTA (table 3.1), ranging from 0 to 88,830 jobs/km2. As expected, job density is at its highest in the CBD; while lower density employment centres emerge in Mississauga and Brampton. As low job density reflects a lack of work-based commuting destinations, we expect that a higher job density in these neighborhoods will be associated with higher transit use.

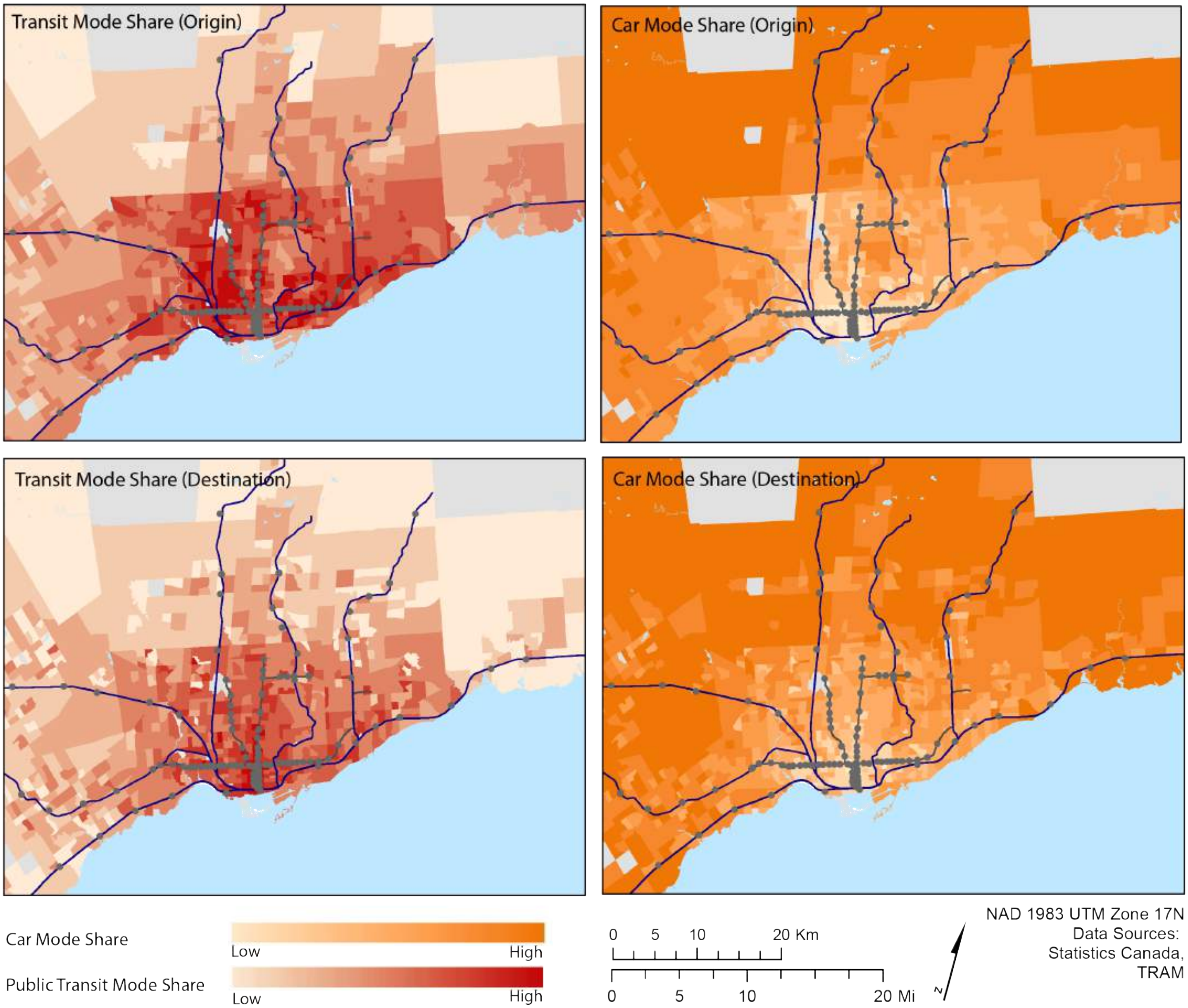
The final built environment characteristic considered in this study is Walk Score. The literature suggests that neighborhoods with dense street grids, mixed land use, and a variety of local amenities are most appealing to pedestrians (Cervero & Kockelman, 1997; Ma & Chen, 2013). As a proxy for land use mix, and the convenience of walking to complete daily tasks, we use Walk Score. Walk Scores for each census tract were derived at the postal code level directly from Walk Score (Walk Score, 2017a), and were aggregated at the census tract level using an area-weighted average. With a holistic score of 0-100, higher Walk Score values are associated with more amenities, and provide a convenient and utilitarian walking experience (Walk Score, 2017a). Therefore, we expect Walk Score and transit use to be positively related with highest transit ridership in areas with a high, or very high Walk Score, where local amenities are present, and trip chaining is more convenient (Walk Score, 2017b).

3.1.5 Measuring Transit Share

To predict transit use at the census tract level, two linear regressions are developed which use origin and destination transit share as dependent variables. We calculate origin and destination transit share separately, using the 2011 Census work-based commuter flows data (Statistics Canada, 2011a). To calculate origin transit share, we isolate the number of trips beginning in each census tract, and travelling to all other census tracts. We then divide the number of trips made using transit by the total number of trips made, which derives transit mode share as a percentage. The same methodology is used to determine destination mode share, separating trips based on the census tract of their destination. As it stands, transit mode share and car mode share have an inverse spatial relationship in the GTA. As predicted by precedent literature, the central business district and inner suburbs currently see higher transit mode share than suburban or exurban communities, which are vehicle-dominated. Figure 3.3 below also demonstrates that transit use is most concentrated in the urban core, as many home-work trips appear to terminate in the CBD. It is unsurprising, yet noteworthy, that transit use is higher along rail corridors and in proximity to transit stations as access to transit and jobs are often highest (Chakour & Eluru, 2013)

TTC streetcar, Toronto, TRAM

Figure 3.3: Existing origin and destination mode share, transit and car



In order to determine which independent variables will be tested in the origin and/or destination model, we use a correlation matrix. Highly correlated variables can significantly skew the results of a regression, and therefore we determine that any two variables with a correlation of greater than |0.55| are not to be included together in the model. Additionally, we test variables in the model(s) where the literature best supports their relationship with transit use. The results of this approach develop two distinct, yet comprehensive regressions that explain a large portion of inbound and outbound transit use in all census tracts, which can therefore be used to determine the success of mobility hubs and predict future transit use.

3.2 Results and Discussion

The following discussion outlines the impact of each tested variable on origin and destination transit share. The significance of variables between these models suggests, as expected, that transit mode share within a census tract is motivated by different factors at the beginning and end of a trip. This suggests that some census tracts may experience higher transit use as an origin or destination depending on the characteristics of the population, built environment, and local transit opportunities.

3.2.1 Origin Demand Model

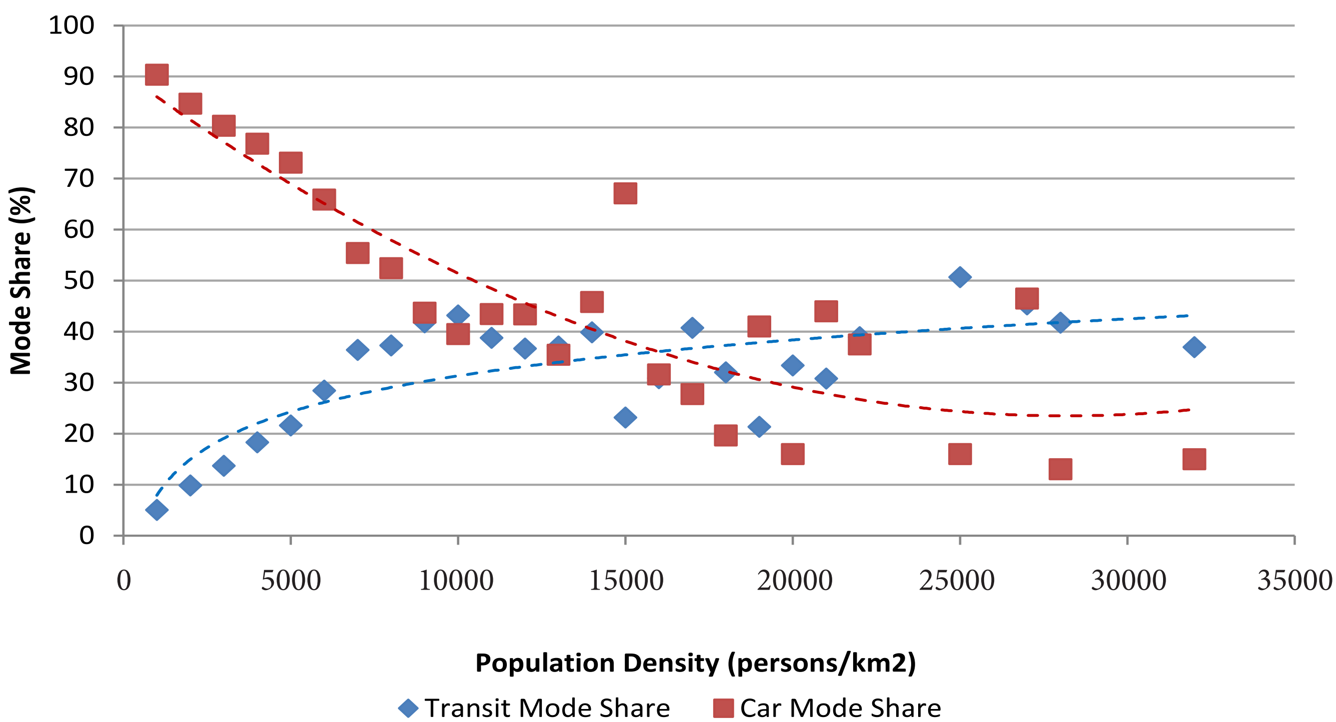
First we analyze origin transit demand using all home-work commutes in the GTA (table 3.3). We find that the availability of local transit near home is a significant predictor of transit use. Walkable access to a subway station is expected to increase transit use by 5% when all other variables are held constant at the mean. Additionally, distance to a freeway is positively and significantly related to transit use, increasing transit mode share by up to 0.3% when distance to the nearest highway on ramp increases by 1 km, and all other variables remain constant. While not a direct indicator of transit availability, this suggests that when driving becomes less convenient, possibly through distance to an express freeway, transit may become a more attractive option.

Table 3.3: Model 1 – Transit Mode Share (Origin)

Variables	Coefficient	T-Statistic	Lower Bound (95% CI)	Upper Bound (95% CI)
Constant	1.661*	1.918	-.038	3.360
Subway (Dummy)	5.098**	4.734	2.985	7.211
Population Density	.547**	4.566	.312	.782
Population Density Squared	-.011**	-4.472	-.016	-.006
Job Accessibility	.170**	24.689	.157	.184
Income/Household Factor	-2.182**	-7.305	-2.768	-1.596
Migration/Employment Factor	2.851**	10.041	2.294	3.408
Distance to Highway	.302**	3.885	.149	.454
**** Significant at 95%*** *****Significant at 99%***			**N** 1168 census tracts **R^2** 0.831	

As expected, population characteristics are strongly associated with outbound transit use. With every increase in population density of 1000 people per square kilometer, we predict that transit use will increase by 0.54% while holding all other variables constant. Interestingly, the square of population density is negatively related to transit use, suggesting a parabolic relationship between density and transit use, with a defined peak. Using the formula to calculate an inflection point (y=a/2b) where a is the coefficient of density, and b is the coefficient of density squared; we predict that maximum transit use can be reached at a population density of 23,800 people/km2, above which transit share will decrease by 0.02% per 1000 people/km2, when keeping all other variables constant. There are 22 census tracts across the region denser than this threshold. Located mainly in urban areas such as midtown, downtown Mississauga, and Crescentown, transit share in these neighborhoods is moderately high, ranging from 16 to 62%. The mean population density in the GTA is 5080 people/km2; which describes many inner suburban neighborhoods with mixed residential density. As shown in figure 3.4, car usage in these neighborhoods decreases as density increases, and transit is used more often. Interestingly, this relationship changes in high density neighborhoods, where transit share and car share are both low. We therefore hypothesize that in neighborhoods denser than 23,800 people/km^2, travellers may opt to walk more often as a dense, urban neighborhood may experience shorter commute distances (Suzuki et al., 2013).

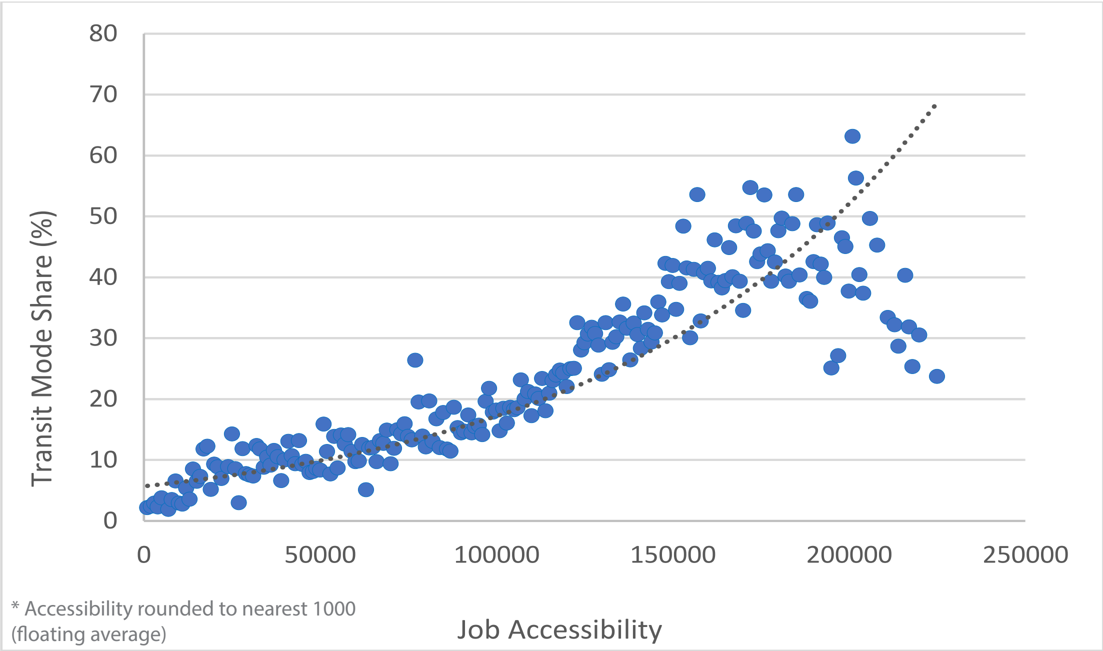
Figure 3.4: Origin Mode Share and Population Density



Social deprivation is a strong predictor of transit use. In the GTA, mean after tax household income is $66791.00 CAD; resulting in concentrated low-income in the downtown core such as Saint James Town, and portions of inner suburbs including Etobicoke, and North York, where transit mode share often exceeds 25%. Improving financial stability - which relates to household income, household size, and the affordability of housing – causes a decrease in transit use as low income families opt for alternative modes to the car, and are less likely to walk to transit (Chia, Lee, & Kamruzzaman, 2016; Foth et al., 2013; Giuliano, 2003). In parallel, areas of high unemployment and recent immigrant groups are associated with higher transit use. Both factors suggest that social deprivation, perpetuated by financial and employment barriers, incentivizes the use of public transit as an alternative to private vehicles. It is therefore imperative that commuters with little alternative to public transit be provided equitable service; connecting to major low-income employment destinations such as Missisauga or Brampton (Legrain et al., 2015).

In addition to the factors noted above, the origin model shows a positive and significant relationship between transit share and job accessibility using transit. With every increase of 1000 accessible jobs near the origin, transit share is expected to increase by 0.2%, while keeping all other variables constant at the mean. While the square term of job accessibility was not significant in the model, figure 3.5 demonstrates a significant and positive relationship between job accessibility and transit share, which peaks at a level of approximately 170,000 jobs. It is important to note that this value represents discounted jobs, which discounts jobs with distance from the point of origin using a gravity-based measure. Average job accessibility using transit in the GTA is 108,000 jobs, however accessibility by transit varies across the region between 170 and 214,000 jobs, with 101 census tracts at a higher job accessibility level than the peak threshold of 170,000 jobs, most of which are located in the CBD.

Figure 3.5: Job Accessibility – GTA Census Tracts



In addition to the variables included in the origin model, several variables were deliberately excluded from further study. We exclude service frequency due to an unacceptably high correlation of 0.69 with job accessibility by transit. The decision to include job accessibility and not service frequency at the origin was grounded by existing literature, suggesting that job accessibility is highly relevant to transit share and can serve as proxy for other variables (Foth et al., 2013; Gutiérrez et al., 2011).

In addition, we also considered the number of rail stations in the census tract, distance to the CBD, number of transit providers, and the number of accessible bus lines. The above variables were excluded from study as they were not statistically significant in the model. Interestingly, distance to a GO station is not a statistically significant predictor of transit use, suggesting that the existing configuration of GO lines, which mainly flow into Union Station at a low frequency, may not sufficiently accommodate the needs of peripheral commuters who do not need to connect into the CBD.

Discussion of Findings (Origin)

The results of the model suggest that although service availability is important at the origin, not all transit options are valued equally. We find that the ability to walk to a subway station is a draw toward transit use. Despite the significance of this relationship, the Toronto Transit Commission operates three subway lines, leaving only nine percent of centroids in the region walkable to a subway station. With only one regional transit agency currently offering 16 commuter train routes across the region, most unconventional commuting paths that do not connect with the CBD are underserved by regional transit, potentially limiting its significance in the model, and its utility to many commuters. This study also confirms existing research which suggests that being able to walk to or from transit increases its use, and facilitates first mile and last mile trips (Cervero & Wu, 1998; Gutiérrez et al., 2011; Legrain et al., 2015). It is therefore important to consider the distance between residential neighborhoods and transit options, introducing either major transit lines, or feeder routes to nearby mobility hubs.

This study reveals that socioeconomic status is relevant to transit use for home-work trips, wherein financially strapped households, often with high proportions of recent immigrants in their neighborhood, are more inclined to use transit. In the Greater Toronto Area, neighborhoods surrounding the CBD, as well as many inner suburban communities are considered socially deprived, with after tax incomes falling well below the $31,835 LICO (low income cut-off) for a family of four (Statistics Canada, 2015). Although transit is documented as a more affordable option to private vehicles for low income families (Garrett & Taylor, 2000), Metrolinx acknowledges in the Big Move plan that long distance commutes, especially those crossing regional boundaries and spanning multiple transit providers are costly for riders (Metrolinx, 2008b). It is imperative to therefore consider frequent service originating from socially deprived neighborhoods, with fare integration that promotes affordability, and strives to make transit available to those who need it most.

The results of this study find that maximizing transit use through population density is a delicate balancing act. Low density environments do not facilitate transit. A combined lack of local demand, and the resulting limited transit availability creates a viscous cycle affecting many outer suburbs of the GTA. On the other end of the spectrum, neighborhoods with densities above 23,000 people/km2 such as Saint James Town are found to be too dense to maximize transit ridership. Neighborhoods within this density range often have a land use mixture and street density that is more conducive to walking (Henao, Piatkowski, Luckey, Nordback, & Marshall, 2015; Suzuki et al., 2013), resulting in decreased transit use. The model therefore determines that densification below this peak threshold is conducive to transit ridership at the origin, and provides a local population that can effectively support, and utilize transit.

Home and work locations in a neighborhood motivate work-based commutes to take place. We find in the origin model that job accessibility and population density appear to have a similar parabolic relationship, with an ideal accessibility by transit of 100,000 to 170,000 discounted jobs (figure 3.5). In the GTA, neighborhoods within this ideal threshold are confined generally to subway corridors, as the subway provides rapid transit with many opportunities for boarding and alighting; increasing accessible employment destinations using transit. It is evident that GO transit does not facilitate the same job accessibility, and therefore changes to the density of suburban stations, frequency, stop locations, parking, and adding routes through major employment centres is likely to significantly increase both job accessibility and the appeal of GO transit across the region, creating a more complete and connected network.

It is evident from this model that origin demand is impacted by a series of factors – with emphasis on demographics of the local population, population density, and proximity to local subway stations.

3.2.2 Destination Demand Model

This section describes the results of a destination demand model, which predicts transit use for home-work trips into each census tract of the GTA (table 3.4). While service frequency was excluded from the origin model due to high correlations, frequency of service is positive and statistically significant in the destination model. We currently see an average peak frequency of approximately 10 vehicles per hour, or one every 6-8 minutes. Although this value seems quite high, we find that many suburban census tracts have 3-5 routes passing through the area every 30 minutes, while the downtown core often sees a higher frequency of 5-10 minutes, and potentially fewer routes in areas served by only one provider (TTC). Census tracts with the highest frequency in the region are those with intermodal stations where the subway arrives every 1-3 minutes, and connects with numerous bus lines. We find that the lowest transit frequency in the region is either in areas with no transit service, or those where only GO lines operate. GO bus lines often run every 30-60 minutes, leaving exurban areas with no local transit, and few accessible routes (TransitFeeds, 2017). These results show that high service frequency can be obtained by either high frequency routes, or many routes at a slightly lower frequency. While both options make transit available, it is important to note the possible distinctions. With an increase in average service frequency of 1 vehicle per hour across the census tract, we predict an increase in transit share of 0.75%. In areas currently underserved by transit, increasing average frequency at the census tract level is more manageable, and therefore this outcome is highly relevant to outer suburbs and areas with low service frequency.

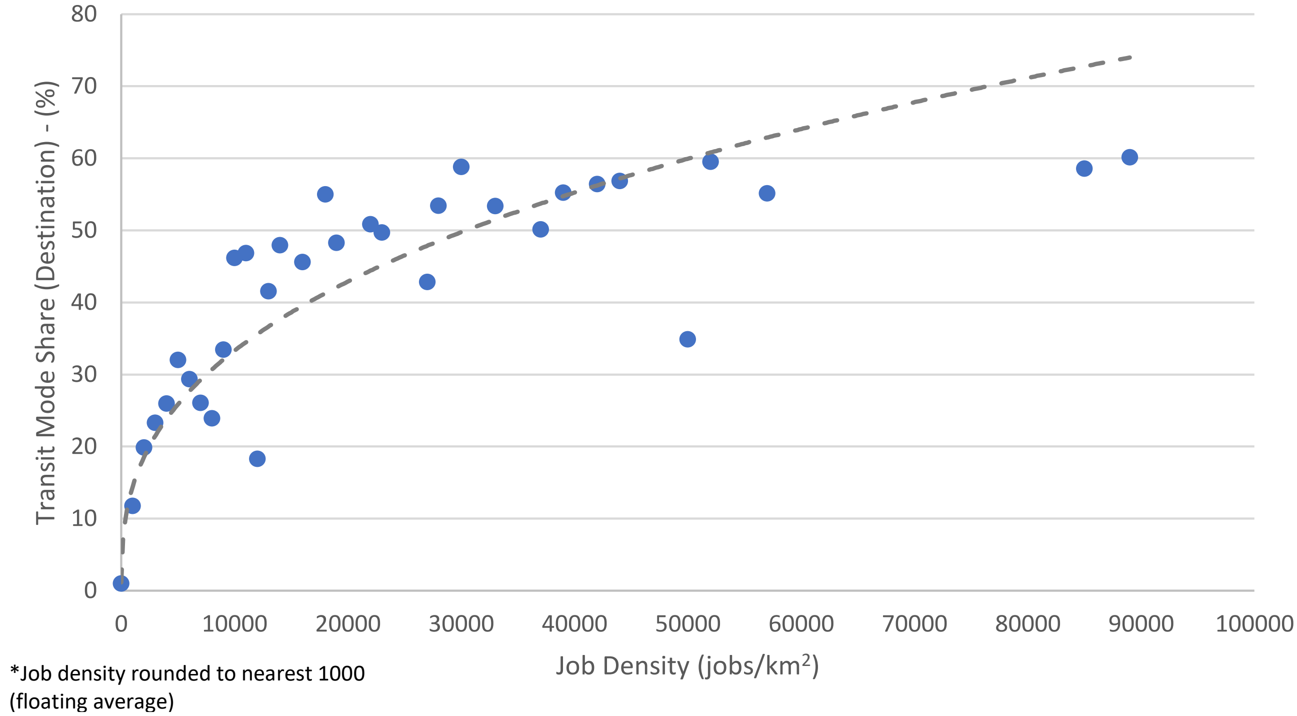
Toronto transit hub Union Station, TRAM

Table 3.4: Model 2 – Transit Mode Share (Destination)

Variables	Coefficient	T-Statistic	Lower Bound (95% CI)	Upper Bound (95% CI)
(Constant)	-3.823**	-4.365	-5.541	-2.105
Worker Accessibility	0.034**	6.800	0.024	0.044
Job Density	0.758**	7.002	0.545	0.970
Job Density Squared	-0.006**	-4.105	-0.010	-0.003
Walk Score	0.103**	7.662	0.077	0.129
Subway (Dummy)	10.216**	10.444	8.297	12.136
Service Frequency	0.747**	22.657	0.682	0.811
Distance to Highway	0.167*	2.251	0.021	0.312
**** Significant at 95%*** *****Significant at 99%***		**N** **R^2**	1168 census tracts 0.823	

The model shows that job density is positively and significantly related to transit use, revealing that an increase in job density of 1000 jobs/km2 increases transit share by 0.75%. Similar to population density, the square term of job density was tested to better understand its relationship with transit share. The square of job density is negatively related to transit share, and therefore the positive relationship between job density and transit use peaks at 63,200 jobs/km2, above which we expect a decrease in transit share (figure 3.6). There are only two census tracts in the GTA with job densities higher than this threshold. As can be expected, both census tracts are located in the CBD near Front Street and University Avenue, and have high pedestrian mode share as high residential and job density make walking a convenient option (Metrolinx, 2015). Across the region, however, average job density is only 1,700 jobs/km2. In Toronto, employment centres are concentrated in the downtown core, and in nearby cities such as Mississauga, and Brampton (Legrain et al., 2015). This finding is further supported as worker accessibility is a significant predictor of transit mode share. With an increase of 1000 workers who can access a destination by transit, transit use increases by 0.03% when all other variables are held constant at their mean. While this coefficient is surprisingly small, it points to the importance of having sufficient access to workers at a job location to support a local transit service.

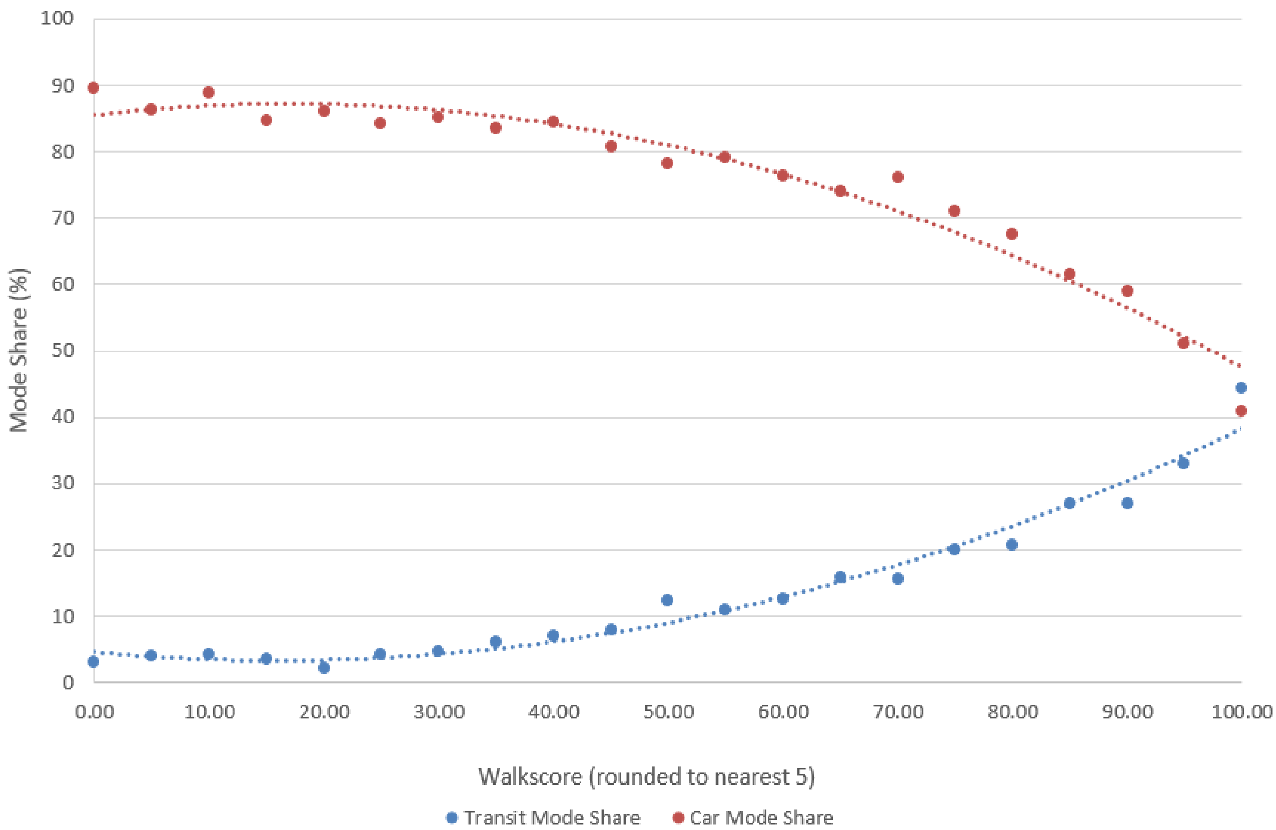
Figure 3.6: Transit share and job density at trip destinations (census tract level)



The final variable considered in the destination model is Walk Score. The results of the model find that for every increase in Walk Score of 10 points, transit mode share is expected to increase by 1%. Figure 3.7 demonstrates that higher Walk Score values are associated with higher transit use, and proportionally lower car use. While the average Walk Score in the GTA is 60, designated as "somewhat walkable" (Walk Score, 2017a), figure 3.7 also shows that transit share increases more with each Walk Score point in neighborhoods with above average Walk Scores. It is believed that this relationship exists at the destination as a higher Walk Score results in more local amenities, and it becomes unnecessary to use a car to perform daily errands once at work.

Toronto central business district, TRAM

Figure 3.7: Car and transit mode share in relation to average Walk Score of the destination



Walkable access from a subway station to work (of 1 km or less) is expected to increase transit use by 10.2% when all other variables are held constant at the mean. Additionally, distance from work to a freeway onramp is positively and significantly related to transit use, increasing transit mode share by up to 0.2% when distance to the nearest highway on ramp increases by 1 km, and all other variables remain constant. These findings suggest that transit is used primarily when it is made more convenient and accessible, but also when other modes are less convenient, or travel is less direct (Shen, Chen, & Pan, 2016).

Discussion of Findings (Destination)

The results of the destination model show that access to transit is relevant at both trip origins and destinations. We find that proximity to a subway station is significant in both models, and therefore supports previous research suggesting that transit is most likely to be used when it can be accessed on foot at both the beginning and end of a trip (Lindsey et al., 2010). The significance of service frequency varies between the models. We find that high transit frequency near places of work incentivizes transit use. As it stands, the highest service frequency in the Greater Toronto Area lies in the CBD and along existing subway routes, which run every 3-5 minutes during peak hours. The results of this study show, however that peak service frequency in the outer suburbs is very low, at 20 to 90 minutes in many neighborhoods. To improve this gap in service frequency, budgetary constraints limit the blanket increase of frequency throughout the network; and therefore, a pilot study analysing ridership throughout the outer suburbs of the GTA is recommended. Our results suggest that routes with connections to major transit hubs, employment centres, or regional destinations with high peak frequency will see high ridership, and therefore targeted service frequency increases along suburban routes between 6 and 9 am is likely to cultivate transit ridership.

When incentivizing home-work trips by transit, it is important to consider the first mile and last mile, or the trip from home to transit, and from transit to the destination. This study reveals that the convenience of walking near one's place of work, proxied by Walk Score in the model, is highly relevant to using transit to get to work. This suggests that a pleasant walk along the "last mile" or final stage of a commute trip, providing opportunities for trip chaining through mixed land use incentivizes transit use, and decreases the perceived necessity of the car (Gutiérrez et al., 2011; Hurst & West, 2014; Lachapelle et al., 2011). Therefore, in neighborhoods with high job density and accessible transit, considering the walkability of the streetscape, and the local opportunities for trip chaining is important. Although a mixture of amenities is positive in many neighborhoods, we specifically recommend high land use mixture in employment hubs, as it is likely for errands to take place during or after the work day, prior to a return commute.

While population density is critical at home locations; job density is statistically significant at the destination in order to facilitate work trips by transit. Job density in the GTA is highly concentrated in the CBD, Mississauga, Brampton, and North York (Rexdale and Black Creek), with density lower than 1000 jobs/km2 across the rest of the GTA. This concentration of job density severely limits transit use as a destination for most neighborhoods. There are two possible solutions to increasing transit use under these conditions. Firstly, high frequency transit can be provided in neighborhoods with moderate density, bringing in potential employees from currently underserved neighborhoods. Alternatively, policy interventions drawing employers to other neighborhoods with sufficient transit to support inbound trips can create new employment centres in the region that are well-supported by transit.

While each of these variables are independently relevant to transit use, the main takeaway from this study is that increasing transit mode share goes beyond simply providing transit in a region. In neighborhoods with a high residential population, the demographics of the region will dictate the transportation needs of the population (origin mode share), while job density will drive inbound commute trips (destination mode share). Land use mixture, proximity to transit, and frequency of service support this density, and must be adjusted to the needs of the residents and workforce. Within the GTA, Metrolinx has identified 51 mobility hubs that have been developed to facilitate the transit-friendly environment this study seeks to capture. Using the origin and destination models derived in this study, the next section will apply them to all mobility hubs in the GTA, and categorize hubs based on their relative success as transit-friendly origins and destinations.

Bus service along Lawrence Ave., TRAM

4 MOBILITY HUB ANALYSIS

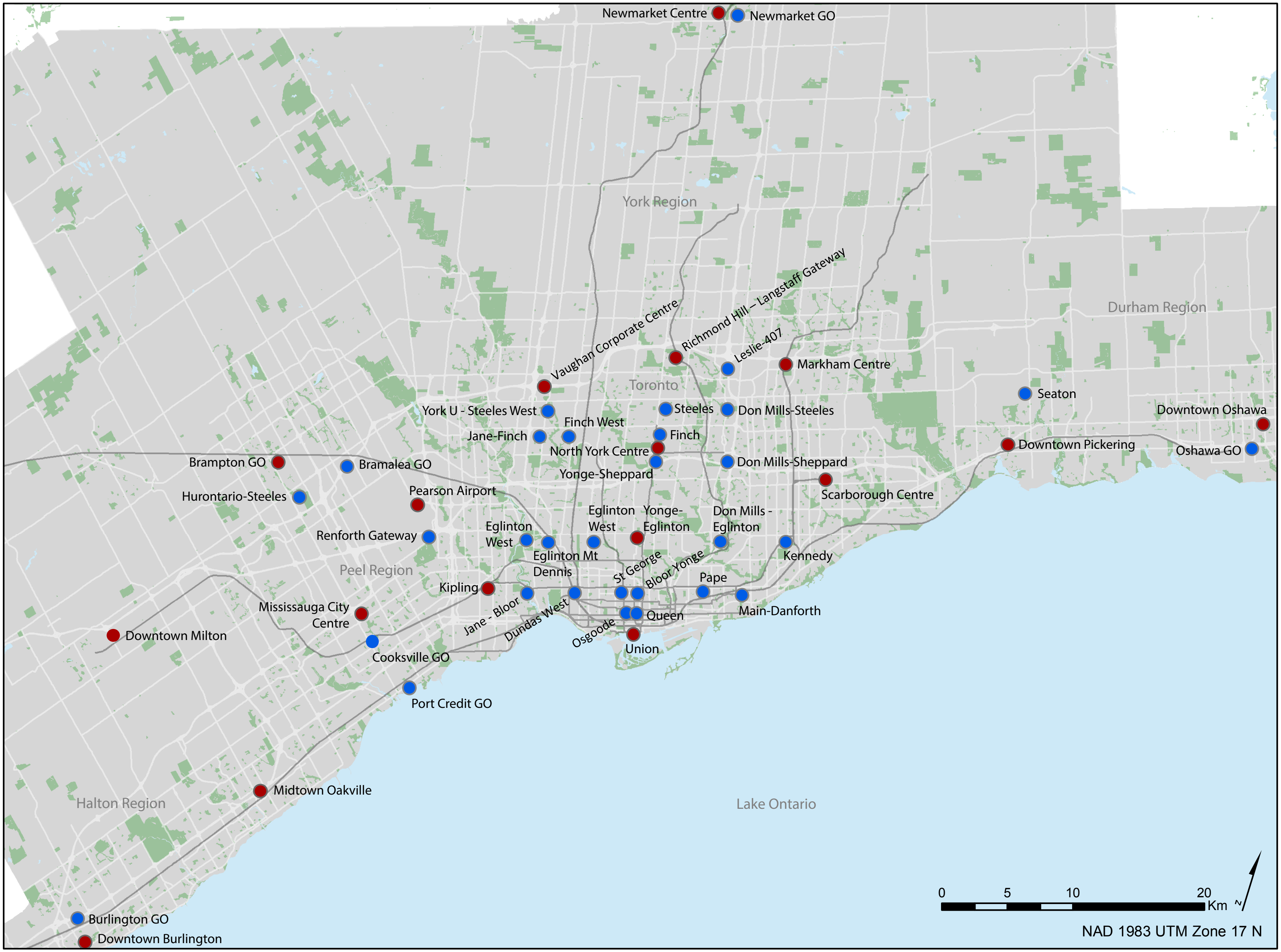
4 Mobility Hub Analysis

In this section, we seek to apply the transit demand models generated above, and approximate existing origin and destination mode share for all mobility hubs in the Greater Toronto Area (figure 4.1). Using these results, we then categorize each mobility hub based on its existing performance, and propose a slate of recommendations for each hub, which are expected to improve mode share where it is currently lacking. Figure 4.1 shows the location of 51 mobility hubs in the GTA, and categorizes them as gateway hubs or anchor hubs, based on typologies developed by Metrolinx (Metrolinx, 2015). Mobility hubs are spread across the region, with 20% percent in the inner city, 40% in the inner suburbs, and 40% in the peripheries of the region.

Although Metrolinx leads the planning of Mobility Hubs, they are only in control of route selection and service frequency. Therefore, coordination with local municipalities to apply necessary zoning changes, set density targets, or encourage certain land uses are essential to encourage the success of the hubs as future origins and destinations.

Oshawa GO Train Station/Mobility Hub, TRAM

Figure 4.1: Context Map of GTA Mobility Hubs



Anchor Hub Gateway Hub Existing Rail Network

4.1 Data and Methods

Using the results of the origin and destination models developed in the previous section, the current origin and destination demand for each mobility hub in the GTA can be calculated. We first calculate a network buffer of 1 km from the centre of each hub using the street network, which produces an irregularly shaped buffer whose size is dependent on street density. Network buffers are preferable to a straight-line radius, as proximity to transit can be assessed using a walkable distance along the existing street network (Gutiérrez et al., 2011). We use an area-weighted average of the variables attributed to each census tract within the network buffer. Each mobility hub is then given an average value for each of the variables in the origin and destination models. To determine the existing origin and destination demand for each hub, we then multiply attributes of each census tract by their respective coefficients in the model. The results of this step are then summed, and the value of the model constant is added. This step is performed separately for the variables within the origin and destination models thereby developing a predicted origin and destination transit mode share for each mobility hub.

Despite using an area-weighted average, the accuracy of the resulting mode share predictions is slightly limited. As the data predicting transit share is averaged to an entire census tract, there is a level of aggregation which does not reflect the characteristics of each hub specifically, but instead summarizes the census tracts that its buffer intersects. This limits the accuracy of our predictions in areas where census tracts extend far beyond the mobility hub, and may cover several neighborhoods of different characteristics. This is most problematic in outer suburbs, as census tracts are often much larger than in the urban core. However, our findings have been checked against the approximate mode share of each hub produced by Metrolinx (Metrolinx, 2016). Although our study uses a larger buffer around each hub, the mode share of 15 hubs were randomly verified, and the results from this study were generally within 5% of predictions made by Metrolinx (Metrolinx, 2016). Therefore, the predictions and recommendations made in this paper are generally applicable and useful to GTA planning agencies, and are grounded by multiple data sources (Metrolinx, 2016; Statistics Canada, 2011b).

To determine the impact of potential improvements to transit demand, variables within each model are adjusted based on hypothetical, yet practical changes to the local environment. By adjusting one variable at a time, we determine the isolated impact of each variable on transit demand, and can therefore propose improvements that are specific to each mobility hub. To test potential policy interventions, we increase the current value of each variable in the model four different ways; by 10%, 25%, 50%, and finally equating the value to the regional average. We then compare the difference between the current transit demand for the hub in question, and the adjusted demand to determine the projected change in transit share caused by changing each variable.

Although all variables were adjusted in this exercise, only those which can be actively addressed by policy makers were considered further. Based on precedent literature, this derived five key interventions (Chen & Paaswell, 2008; Foth et al., 2013; Gutiérrez et al., 2011; Hurst & West, 2014; Legrain et al., 2015):

- Incentivize home location (population density, worker accessibility)
- Increase job density
- Improve built environment (walkability, accessibility, etc.)
- Increase transit service frequency
- Build subway station in or in proximity to the hub in question

We recommend a combination of the above interventions for each mobility hub based on how much transit demand increases when factors were adjusted. If demand increased consistently based on all four recommendations, and if the application of this intervention is practical for the hub in question, it is recommended as a mobility hub when potential changes are made.

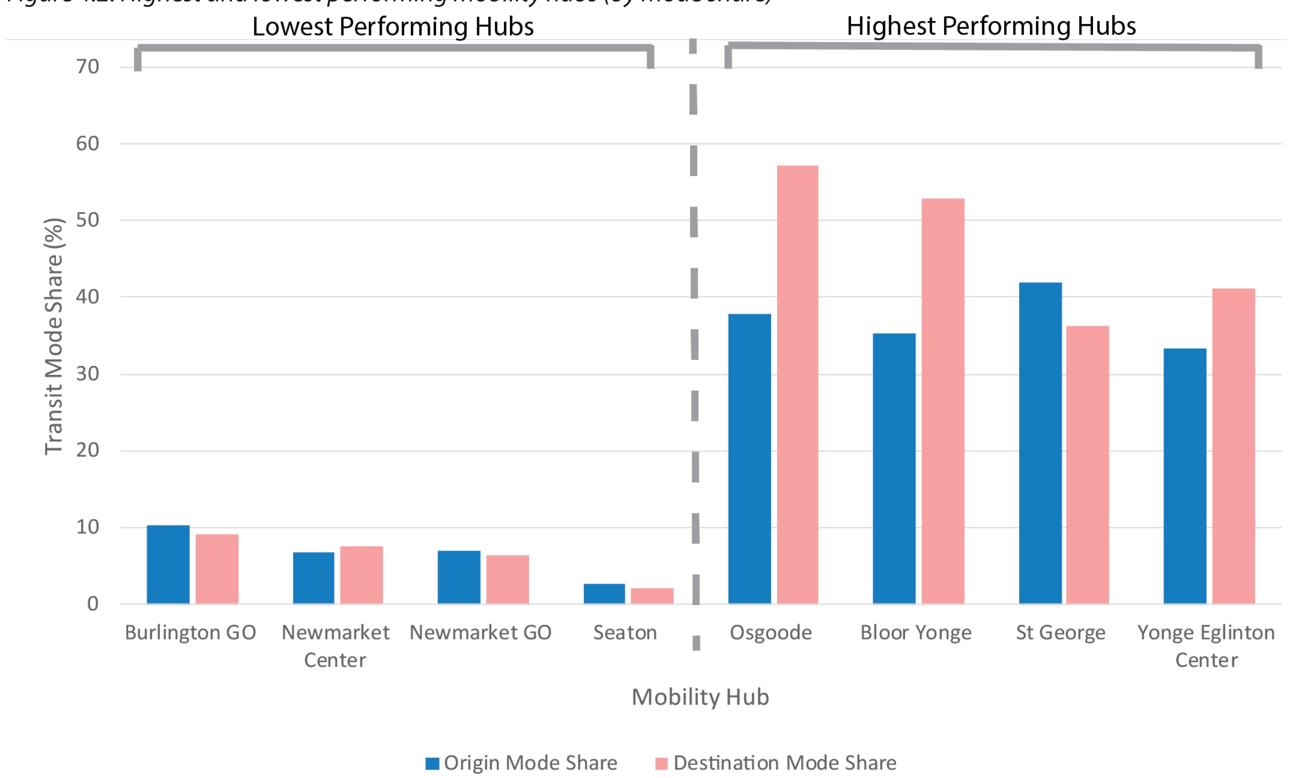
It is important to note that not all 51 mobility hubs have been considered for further study. The Greater Toronto Area was selected for this study, which excludes three mobility hubs in Hamilton, Ontario. An additional 7 hubs are excluded from study as some of the data for one or more census tracts crossing the hub were unavailable. This leaves 41 mobility hubs which have been considered in the remainder of this study. Finally, four mobility hubs have been selected for further exploration, with one hub falling into each category noted in table 4.1. The characteristics of each of these hubs have been presented in tables 4.3 – 4.6, and use transit and built environment characteristics including land use mixture to support given policy recommendations (DMTI Spatial Inc., 2017).

4.2 Results

4.2.1 Mobility Hub Performance

Figure 4.2 demonstrates the location of the lowest and highest performing mobility hubs in the GTA, based solely on average transit mode share. Average mode share is calculated as the average of current origin and destination mode share, and provides a rough indication of current hub performance.

Figure 4.2: Highest and lowest performing mobility hubs (by mode share)



While the highest performing hubs have a high average transit mode share, many of these, including Osgoode and Bloor-Yonge, are imbalanced in their origin and destination transit use. To improve upon these concerns, each of the mobility hubs considered have been divided into one of four categories based on their identified areas of weakness as a hub. A mobility hub is most successful when encouraging transit use as an origin and a destination (Metrolinx, 2011). Therefore, hubs are categorized based on policy interventions targeted at increasing transit use from home, to work, both, or neither, depending on current performance. Additionally, table 4.1 notes the level of development currently underway at each mobility hub. While some hubs are already well-developed, others are either the subject of future development plans in the Big Move, or are largely undeveloped. This characterization impacts the feasibility and prioritization of proposed interventions, and greatly extends the timeline for enacting proposed changes.

In table 4.1, hubs are categorized as "needing improvement" if one or more of the following criteria applies:

- Mode share at either the origin or destination falls below 25%
- The hub is imbalanced, with a difference between origin and destination mode share of greater than 5%.

This threshold was chosen based on an average transit mode share in the GTA is approximately 25% across the region. Accordingly, the recommendations made are realistic, therefore interventions and policy recommendations can therefore be suggested and applied more specifically, avoiding a blanket approach which does not consider the specific characteristics of the hub in question.

Figure 4.3 demonstrates the results of table 4.1 spatially. The symbols showing each mobility hub have been customized based on the slate of policy recommendations which would benefit the hub most. For hubs where a subway station has been recommended, these hubs fall in proximity to existing subway lines where an extension of existing or planned subway lines is feasible. In cases where an increase in service frequency is recommended, only hubs with exiting service connected to major destinations are considered.

University Avenue, Toronto, TRAM

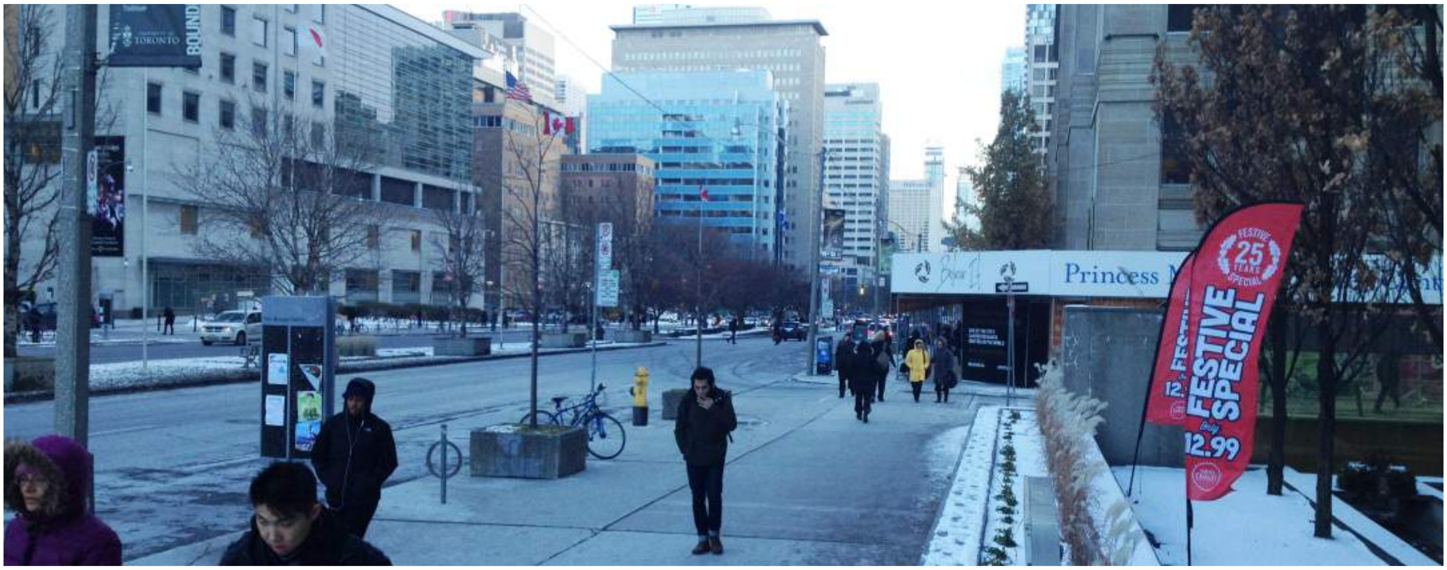
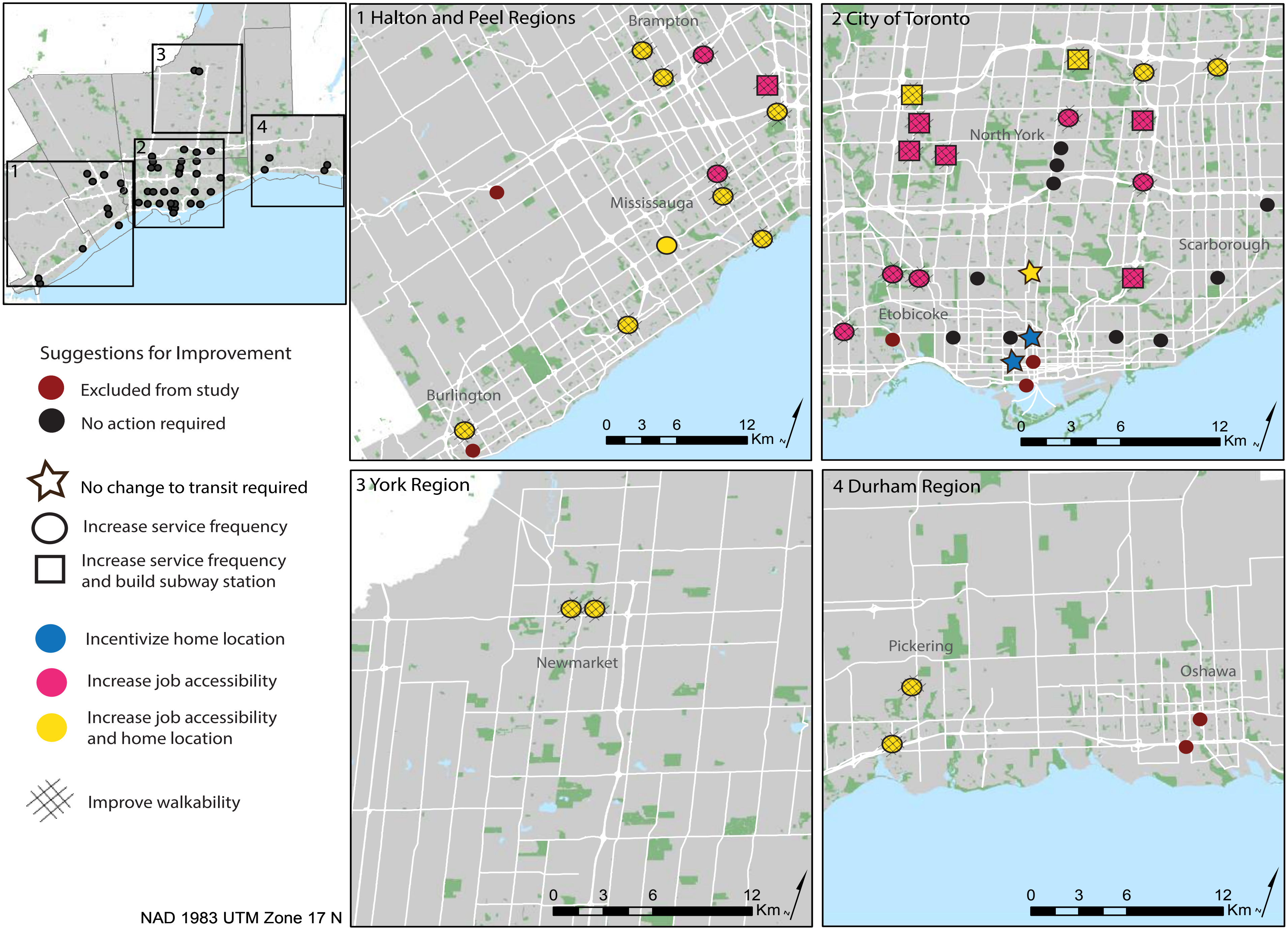


Table 4.1: Mobility Hub Performance and Suggestions for Improvement

Mobility Hub	Policy Interventions					
	Land Use Mix/Walkability	Job Availability	Subway Access	Service Frequency	Residential Density	Time Frame to Hub Status
Requires Improvement as Origin and Destination						
Port Credit GO	+	Δ	NA	+	+	IPR
Cooksville GO	+	Δ	NA	+	+	IPR
Midtown Oakville	+	+	NA	Δ	+	IPR
Renforth Gateway	+	Δ	NA	+	+	IPR
Downtown Pickering	+	+	NA	Δ	+	-
-Downtown Brampton	+	Δ	NA	+	+	-
Leslie - 407	+	+	NA	+	+	-
Hurontario-Steeles	+	Δ	NA	+	+	-
Vaughan Corporate Center	+	+	Δ	+	+	IPR
Burlington GO	+	+	NA	Δ	+	IPR
Richmond Hill/Langstaff	+	+	Δ	+	+	IPR
Markham Center	+	Δ	NA	+	+	-
Newmarket Center	+	Δ	NA	Δ	+	-
Newmarket GO	+	+	NA	Δ	+	-
Seaton	+	+	NA	+	+	-
Requires Improvement as Origin						
Osgoode	NA	NA	NA	NA	Δ	++
Bloor Yonge	NA	NA	NA	NA	+	++
Yonge Eglinton Center	NA	Δ	NA	NA	+	++
Requires Improvement as Destination						
Kipling	+	+	NA	Δ	NA	IPR
Don Mills Sheppard	+	+	NA	Δ	NA	++
Jane-Eglinton	+	+	NA	Δ	NA	IPR
Eglinton Mt-Denis	+	+	NA	Δ	NA	IPR
Jane-West	+	+	Δ	+	NA	-
Steeles	+	+	NA	+	NA	++
Don Mills - Steeles	+	+	Δ	+	NA	-
Don-Mills Eglinton	+	+	+	Δ	NA	IPR
Mississauga City Center	+	+	NA	Δ	NA	++
Finch West	+	+	+	Δ	NA	-
York U-Steeles West	+	+	Δ	+	NA	IPR
Toronto Pearson Airport	+	+	Δ	+	NA	IPR
Bramalea GO	+	+	NA	Δ	NA	++
Does Not Require Improvement						
St George	NA	NA	NA	NA	NA	++
Dundas West Bloor	NA	NA	NA	NA	NA	++
North York Center	NA	NA	NA	NA	NA	++
Eglinton West	NA	NA	NA	NA	NA	++
Finch	NA	NA	NA	NA	NA	++
Pape	NA	NA	NA	NA	NA	++
Scarborough Center	NA	NA	NA	NA	NA	++
Yonge Sheppard	NA	NA	NA	NA	NA	++
Main-Danforth	NA	NA	NA	NA	NA	++
Kennedy	NA	NA	NA	NA	NA	IPR

+	Positive impact on mode share	-	Not yet a developed hub
Δ	Top priority intervention	IPR	Development Underway
NA	No action required	++	Currently a developed hub

Figure 4.3: Final recommendations to improve transit demand at mobility hub



The results of adjusting for potential policy interventions have revealed several key trends. Firstly, many of the mobility hubs which we deem currently successful are situated within either the downtown core of Toronto, or its inner suburbs. The resulting high population and employment density of these neighborhoods appears to provide sufficient demand to sustain local transit. These neighborhoods are also serviced by a series of bus lines, dense street grids, and at least one, if not two highly frequent subway lines. Although Metrolinx has launched further improvements at many stations across the GTA, few of the stations we consider successful are under consideration, indicating that the philosophy and success criteria adopted in this study align well with Metrolinx's current operations. Table 4.6 further explores the characteristics of a successful mobility hub, and sets several targets for success that we hope other mobility hubs will one day achieve.

Of the 41 mobility hubs under review, 15 are believed to require improvement as both an origin and destination, and are a top priority for improvement. It is important to note that these hubs sit in the outer suburbs of the GTA, in neighborhoods such as Newmarket, Pickering, and Oakville, characterised by below average density; ranging between 500 to 5000 people/km2. While Metrolinx is also working to improve some stations such as Port Credit, Cooksville, and Oakville; many other hubs in this category are not slated for development in the foreseeable future, and are currently serviced by either zero or one transit provider. As these hubs require improvements at both the origin and destination, there are a series of possible interventions which will increase transit use. The installation of a subway station is expected to have the greatest impact on demand; however this solution is only feasible for select stations which are in proximity to the existing subway network. We urge Metrolinx to consider Richmond Hill/Langstaff Gateway, Vaughan Corporate Centre, York U, Finch West, and Jane-Finch as future subway stations via the extension of the Yonge-University-Spadina subway. This extension would open a travel corridor between Toronto and North York; two dense employment and residential hubs which are currently left isolated from each other. As it happens, the proposed extension of the Yonge Subway includes some, but not all of the hubs mentioned above. It is therefore suggested that frequent feeder bus service run from the Jane-Finch mobility hub to other nearby destinations, as this low-income neighborhood is likely to remain without subway access. Beyond subway development, it is recommended that job availability and population density quotas be implemented in many of low density hubs such as Newmarket GO, Markham Centre, and Renforth Gateway, where real estate investment is currently underway (Realtor MLS Listings, 2017). Finally, service frequency is a significant issue in many mobility hubs. Hubs in the furthest peripheries of the GTA including Newmarket, Pickering, and Burlington have very low peak service frequency of only one bus or train every 20 – 30 minutes. As these hubs are primarily served by GO transit lines running into Union Station, we recommend either an increase in service frequency, or a diversification of routes, connecting these hubs to other major destinations in the region.

With slightly more success, three hubs have been identified as successful destinations, but weak origins. Surprisingly, these hubs - Osgoode, Bloor-Yonge, and Yonge-Eglinton - are all located in the downtown core, and are well served by rail and bus transit. The Greater Toronto Area has undergone suburbanization of the population, leaving the downtown core primarily as a popular commuting destination despite the suburbanization of employment in the city (Legrain et al., 2015). To improve upon this, the model results demonstrate a weakness in residential density around these stations, which needs to be addressed by incentivizing home location to increase origin demand. Figure 4.4 explores this intervention further using Yonge Eglinton centre as a case study.

Finally, thirteen hubs are categorized as a successful origin, but a weak destination by transit (table 4.1). These hubs are located within the inner suburbs of Toronto, or in adjacent cities such as Brampton or Mississauga. The majority of these hubs such as Kipling, Eglinton, Don Mills, or Finch West are located on or within five kilometers of a subway station, and are therefore serviced by low-frequency feeder bus lines, adding transfer and wait times to daily commutes into the CBD. The model shows that improving transit service is the best improvement for hubs in this category. We believe that increasing bus frequency in these neighborhoods is the highest priority intervention for neighborhoods where subway extension is not possible. Pearson Airport is the largest gateway in Canada, however it currently only connects to Union Station via the Union-Pearson Express. It is therefore recommended that additional transit be developed, connecting Pearson Airport to other dense residential communities including Etobicoke and Mississauga. Figure 4.4 explores interventions to improve destination transit share using the Mississauga City Centre as a case study.

4.3 Case Study Analysis

The following section details one mobility hub from each of the four categories presented in table 4.1. Within each case study, we first present a map of current land use designations, and transit services in the hub. A summary table of all characteristics considered in our transit demand models is also presented, accompanied by a series of recommendations and projected impacts of these policy interventions. In summary tables 4.3 to 4.6, we use a ranking scheme to place the mobility hub in question among all mobility hubs in the GTA. Table 4.2 explains the symbology used in this ranking process.

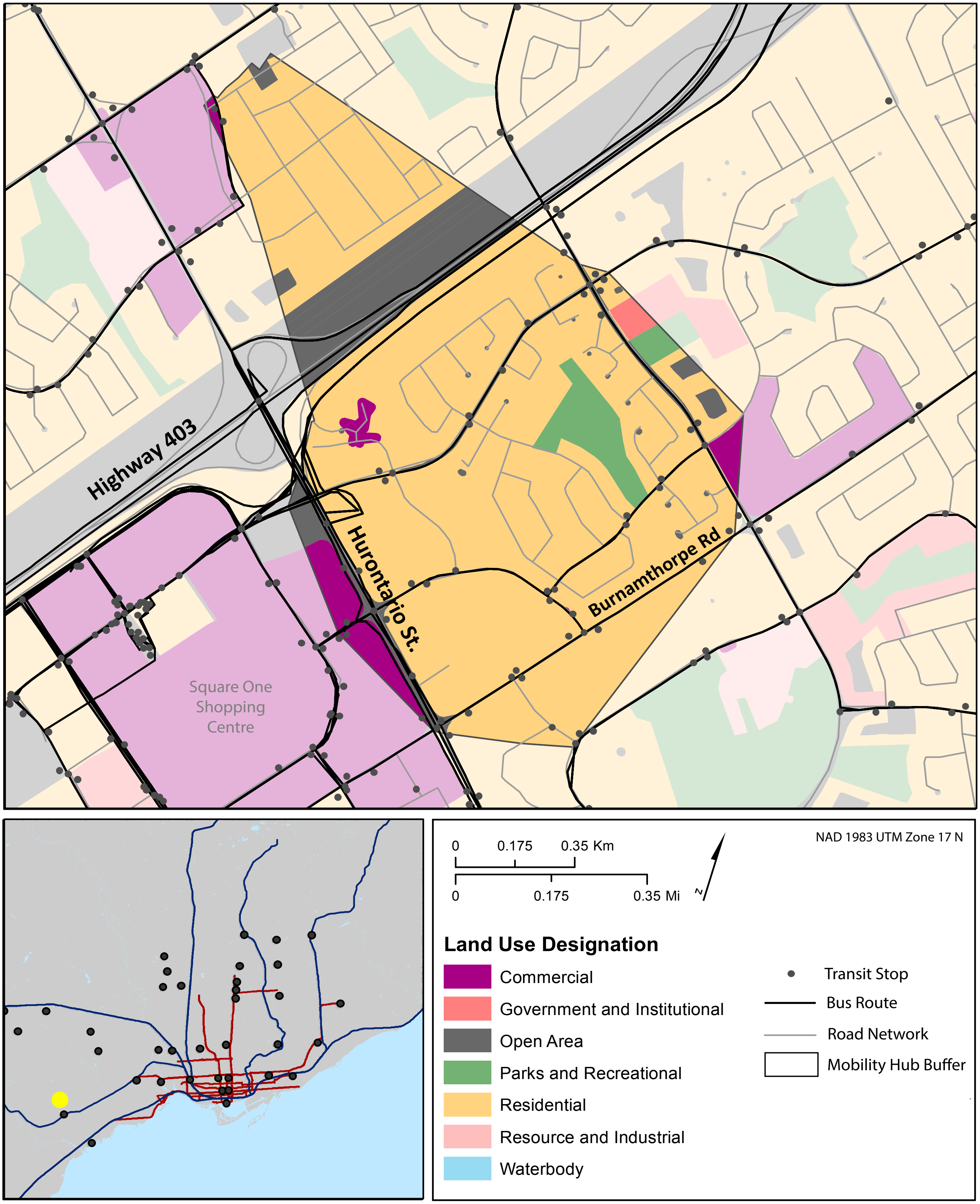
Table 4.2: Explanation of case study rankings

Symbol	Ranking
🟢 (green)	Hub lies in top 10% of all mobility hubs
🟡 (yellow)	Hub lies in top 11 - 25% of all mobility hubs
🟠 (orange)	Hub lies in top 26 - 50% of all mobility hubs
🔴 (red)	Hub lies in bottom 50% of all mobility hubs
⚫ (black)	Hub has the lowest value of all mobility hubs

GO Train Platform, Toronto, TRAM

Case Study 1: Successful Origin, Weak Destination Mobility Hub: Mississauga City Centre

Figure 4.4: Mississauga City Centre Mobility Hub Land Use Profile



Anchored by the Square One Shopping Centre and Square One GO bus terminal, the Mississauga City Centre mobility hub is categorized as an anchor hub, bringing regional GO transit and local MiWay bus transit together in proximity to the bustling Square One retail centre (Metrolinx, 2016). As it stands, the Mississauga City Centre mobility hub sees average mode share in comparison to all hubs in the region.

Table 4.3: Mississauga City Centre Characteristics

Existing Demand	Value	Ranking
Origin Mode Share	26%	● (red)
Destination Mode Share	18%	● (red)
Population Characteristics		
Population Density	5900 people/km^2	● (orange)
Average Income	$58,755.47	● (orange)
Average Household Size	3	● (orange)
Spending more than 30% of income on housing	14%	● (orange)
Percentage of recent immigrants	11%	● (yellow)
Unemployment Rate	9.50%	● (orange)
Built Environment Characteristics		
Walk Score	81	● (orange)
Job Density	3900 jobs/km^2	● (yellow)
Accessible Jobs	129,000 jobs	● (red)
Distance to the nearest highway	1.09 km	● (red)
Subway Station	No	● (red)
Transit Characteristics		
Number of Rail Stations	0	
Average Peak Service Frequency	10 minutes	● (red)
Number of Transit Providers	2	

As an origin, this hub is home to a moderately dense population, with many low density single family homes located within meters of the hub. With below average income and a high proportion of recent immigrants and unemployed residents, this hub is performing well (26%) in origin demand (Foth et al., 2013). Despite its location in the heart of Canada's sixth largest city, job accessibility by transit is surprisingly low, leading to a disappointing and imbalanced destination mode share of 18% (table 4.3). With an average peak service frequency of 10 minutes, made only acceptable by frequent MiWay service, there is little regional transportation during peak hours. Therefore, a targeted increase in GO bus frequency through the Mississauga GO terminal is recommended. By doubling average service frequency at transit stops within the hub between 6 and 9 am, it is expected that inbound transit use will increase by 4.6%. This frequency, however, represents frequency at each stop, and not each route. We therefore specifically recommend that frequency at the Square One GO Bus Terminal, which anchors the hub; be increased. The Waterloo/Mississauga GO route, connecting to York University runs only once per hour during peak frequency (GO Transit, 2017). As it connects several major destinations, we recommend that Metrolinx perform a pilot to increase frequency significantly along this line to 15 minutes, similar to other lines running in the area (Mississauga/North York, 407 West routes). Additionally, increasing frequency between 6 and 9 am on MiWay routes running along Hurontario St and connecting to GO and future Hurontario LRT terminals is also strongly recommended.

Additionally, the walkability of the neighborhood is not ideal for transit use. Figure 4.2 above shows little land use mixture at a human scale. This neighborhood is dominated by residential land use and large city blocks; broken up by the Square One shopping centre, which concentrates many local amenities in one building. It is therefore recommended that land use mixture be increased by diversifying available amenities within a walkable distance. It is predicted that a land use change, resulting in a 10% increase in the Walk Score of the neighborhood, would increase transit mode share by at least 1%. While Square One provides numerous retail services, there are few daily amenities located outside of the mall; and those that are in place are generally big box stores, which are not conveniently located in relation to employment centres, including City Hall.

Finally, while Mississauga City Centre has undergone significant densification in recent years (Mississauga, 2010), single family homes remain a dominant land use around the hub, and east of the Square One Shopping Centre. In order to increase inbound mode share for work purposes, it is recommended that the number of potential employees who can access jobs in the Mississauga City Centre, as well as the number of jobs available be increased. To do this, it is recommended that the City of Mississauga consider zoning changes in the City Centre to allow for high density, mixed use developments around the hub. Once sustained by a dense employment centre, transit service can also be expanded to currently underserved communities south of Dundas St. and East of Hurontario, connecting Mississauga City Centre to a previously isolated group of potential commuters. We predict that a 25% increase in workers who can access Mississauga City Centre will increase transit share by 2-3% when other factors are left unchanged.

For imbalanced mobility hubs favouring outbound trips, policy recommendations must focus on making destinations accessible, and connecting hubs to nearby residential neighborhoods. By fostering a mixed, dense walking environment and numerous transit opportunities through zoning and density quotas, we expect the balance of these hubs to improve drastically.

Mississauga City Centre Mobility Hub, Google Earth, 2017

Case Study 2: Weak Origin, Successful Destination
Mobility Hub: Yonge Eglinton

Figure 4.5: Yonge Eglinton Mobility Hub Land Use Profile

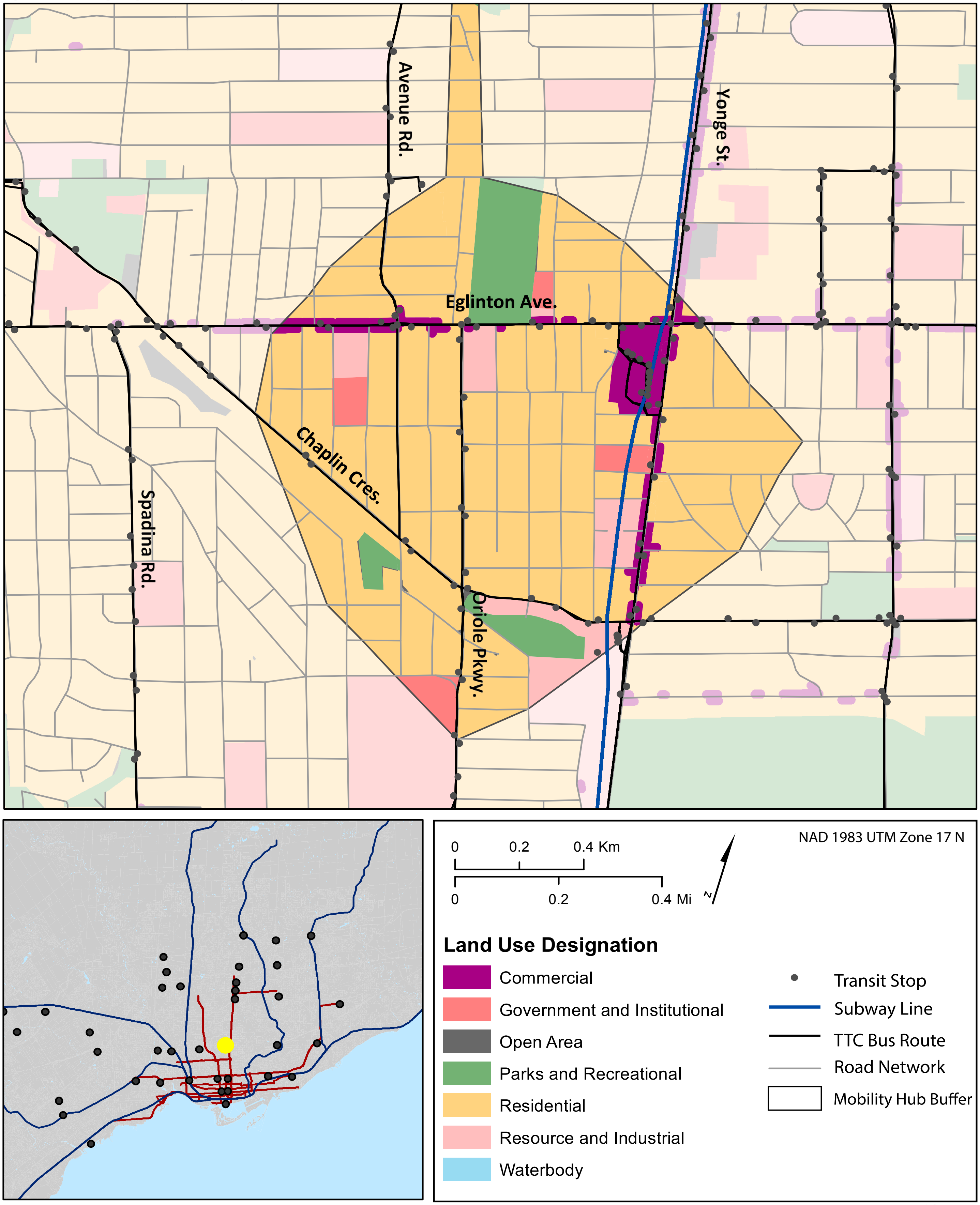


Table 4.4: Yonge Eglinton Hub Characteristics

Existing Demand	Value	Ranking
Origin Mode Share	33%	🟢
Destination Mode Share	41%	🟢
Population Characteristics		
Population Density	7530 people/km^2	🟠
Average Income	$72,413.43	🟡
Average Household Size	2.8	🔴
Spending more than 30% of income on housing	14.70%	🟠
Percentage of recent immigrants	3.60%	🔴
Unemployment Rate	6.1	🔴
Built Environment Characteristics		
Walk Score	93	🟢
Job Density	6770 jobs/km^2	🟡
Accessible Jobs	169,000 jobs	🟡
Distance to the nearest highway	5.1 km	🟢
Subway Station	Yes	🟢
Transit Characteristics		
Number of Rail Stations	1	
Average Peak Service Frequency	3 minutes	🟡
Number of Transit Providers	1	

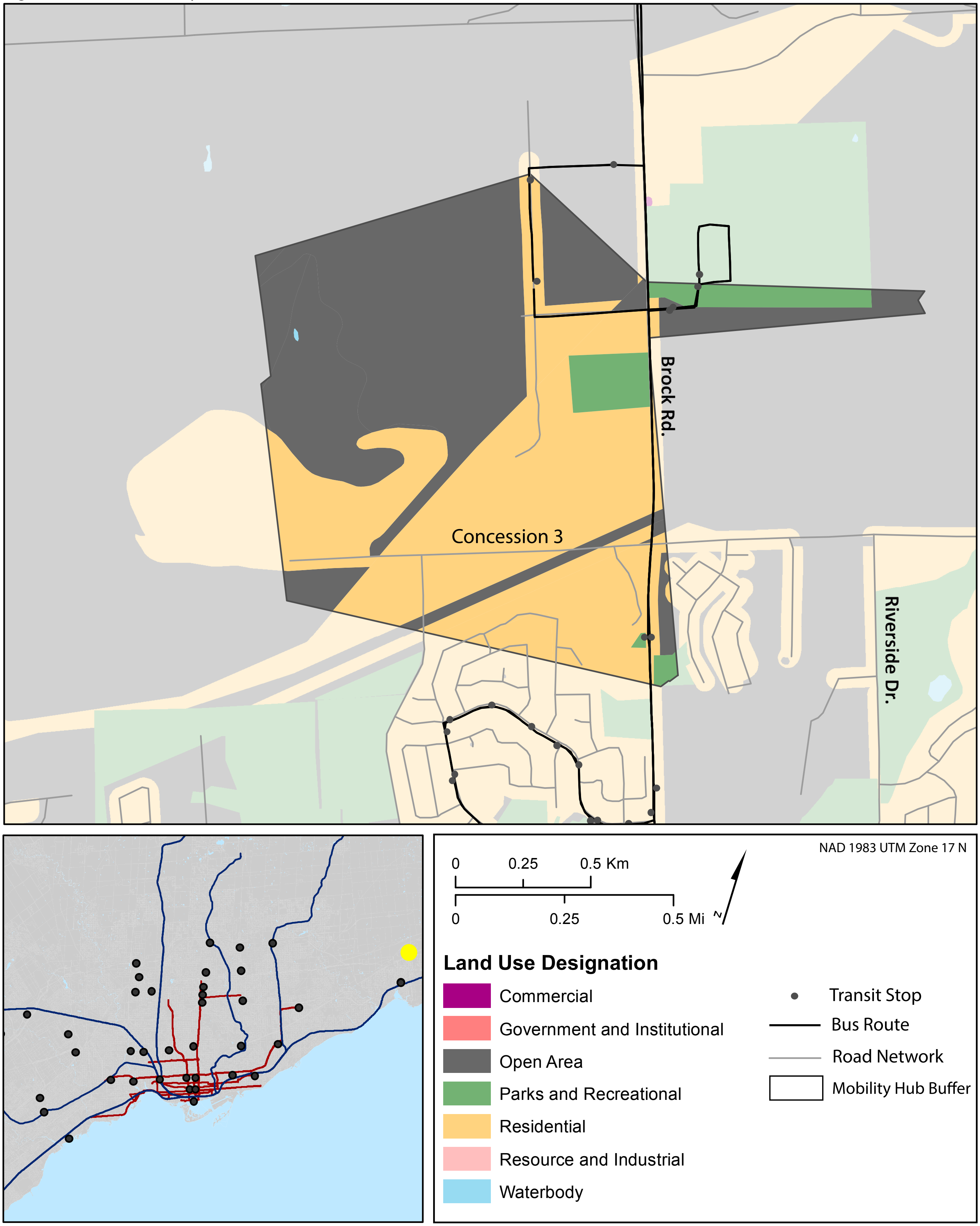
The Yonge Eglinton mobility hub is centrally located within a dense, mixed use employment centre in the City of Toronto. Characterized as an anchor hub by Metrolinx, Yonge Eglinton is anchored by the Eglinton Subway station, which is directly connected to Toronto's main transit centre, Union Station (Metrolinx, 2015). Despite its well-connected location, Yonge-Eglinton sees imbalanced mode share, performing better as a destination than an origin (Metrolinx, 2016).

In order to induce home-work trips, employment opportunities must be reachable by available transit options. Our findings suggest that responding to this concern is both a transit and zoning concern. We recommend that zoning policies be amended to increase residential density caps along the Yonge Street corridor, and in proximity to the Yonge-Eglinton hub. The resulting increase in population density is projected to encourage transit use, and may support higher frequency routes during peak commuting hours. It is expected that a 20% increase in accessible employment opportunities would increase the origin mode share of the hub by 7.2%. Additionally, the presence of a subway station in the region appears to have a significant impact on transit use relative to bus routes, however there is currently no regional transit integration at this hub. Fortunately, Yonge-Eglinton will be an interchange station of the future Eglinton Crosstown LRT, which is currently under construction in the region. With this development, job accessibility and population density are likely to increase significantly as more opportunities will be reachable along the east-west Eglinton corridor (Metrolinx, 2017). It is recommended, however, that Metrolinx consider the introduction of a regional bus route connecting to the Yonge-Eglinton area. With several GO routes terminating at the Finch Subway Station further north, it is possible, yet inconvenient for peripheral travellers from Waterloo or Mississauga to access the Yonge-Eglinton area. With increase in population density, and as the site of a future LRT station, the addition or extension of a GO bus line into this area is recommended for consideration.

Many characteristics of this hub are conducive to transit use, including high walkability and service frequency. However, certain demographic trends in the neighborhood, including high average income and family size, tend to lean against transit use in favour of private vehicles (Foth et al., 2013). With a goal of increase transit use for all commuters, it is recommended that Metrolinx consider a marketing campaign to promote public transit in neighborhoods where the local population may not be accustomed to transit use, similar to the PTV plan in Victoria, Australia (Public Transit Victoria). This and other similar plans are designed not only to advertise transit, but to promote its community-oriented and cost-effective nature, which can appeal to commuters of any income.

Case Study 3: Low Density, Low Transit Use
Mobility Hub: Seaton

Figure 4.6: Seaton Mobility Hub Land Use Profile



The Seaton mobility hub is a true anomaly. Situated north of Pickering, Ontario, and currently lacking any regional transit, Seaton is anchored only by the Seaton and Pickering Golf and Country Clubs. Currently, only one local bus route serves the Seaton hub, provided by Durham Transit, therefore leaving this hub disconnected from any major employment centres. It is therefore unsurprising that Seaton has the lowest transit mode share of all mobility hubs in the region.

It is evident that Metrolinx considers Seaton a planned mobility hub. The Big Move plan identifies Seaton and the Brock Road corridor as areas of long-term transit intensification; specifically with GO regional rail installations (Metrolinx, 2008b). While this intensification is necessary for the success of Seaton as a mobility hub, this action will not likely be sufficient to cultivate sustainable demand for transit. We therefore recommend Metrolinx prioritize studies and further analysis into the Seaton hub to determine whether intensification is a worthwhile investment.

We find that several interventions are necessary to stimulate transit demand through the built environment. Currently a Walk Score of only seven signifies a car dependent neighborhood with little land use mixture. To better integrate land use and transportation in the neighborhood, addressing the land use mixture and street grid density enough to increase Walk Score to a "somewhat walkable" level would increase transit demand by 7%. Finally, increasing both the local population and accessible jobs will incentivize home-work trips to begin and end in the area. This can be achieved through the addition of transit routes to expand accessibility, the densification of the Brock Road corridor, or by incentivizing employment centres to locate in the area.

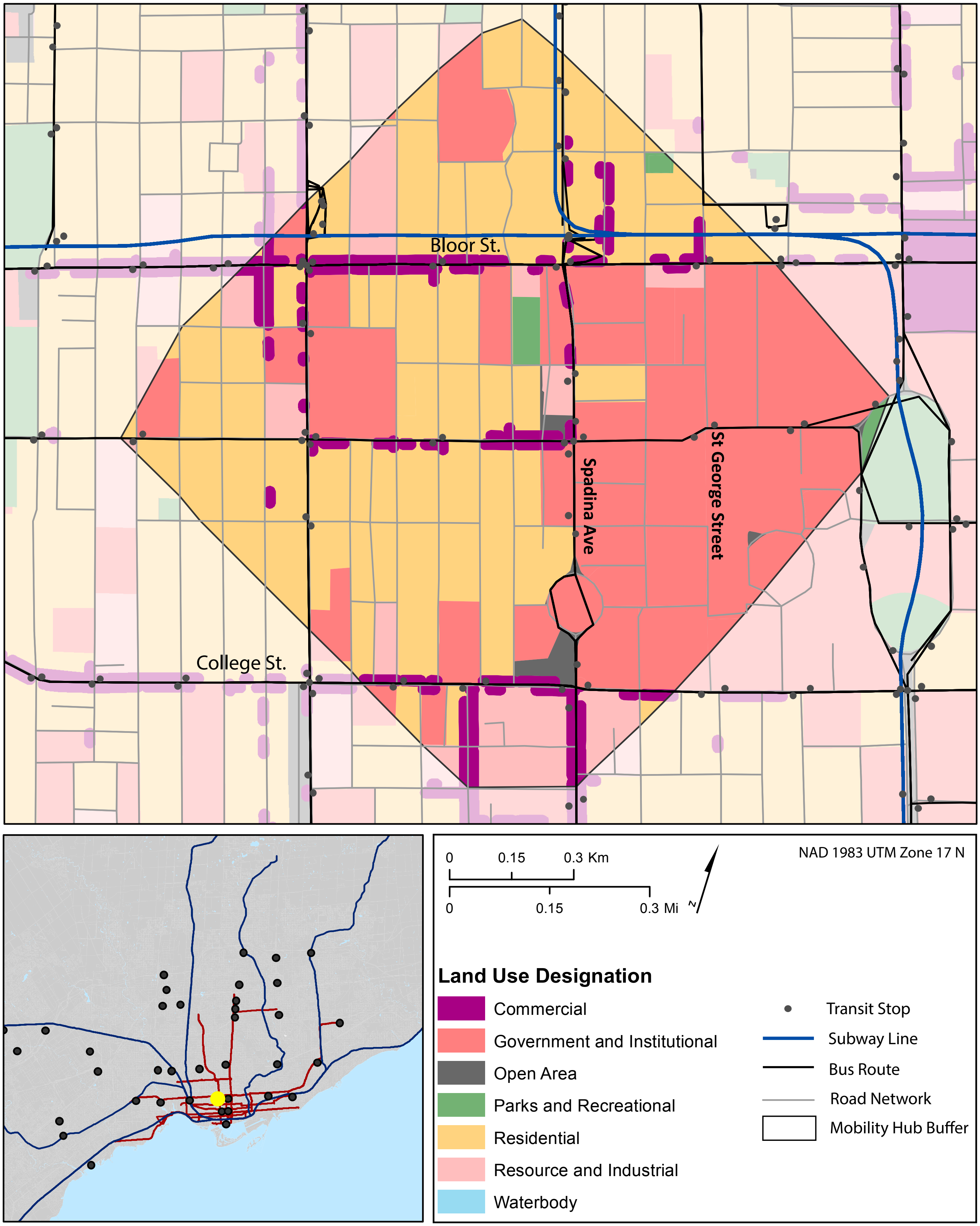
Table 4.5: Seaton Hub Characteristics

Existing Demand	Value	Ranking
Origin Mode Share	3%	●
Destination Mode Share	2%	●
Population Characteristics		
Population Density	530 people/km^2	●
Average Income	$82,114.71	●
Average Household Size	3.2	●
Spending more than 30% of income on housing	7.00%	●
Percentage of recent immigrants	0.13%	●
Unemployment Rate	5.5	●
Built Environment Characteristics		
Walk Score	7	●
Job Density	51 jobs/km^2	●
Accessible Jobs	20,000 jobs	●
Distance to the nearest highway	5.1 km	●
Subway Station	No	●
Transit Characteristics		
Number of Rail Stations	0	
Average Peak Service Frequency	12 minutes	●
Number of Transit Providers	1	

The results of this research also call into question whether Seaton is a prime candidate for the mobility hub title. Metrolinx identifies other station typologies such as destinations and major transit station areas, which do not require the same density, intermodal connections, or drawing power as a mobility hub, but are still sites of well-used transit lines (Metrolinx, 2011). As it remains unclear the exact routing of future transit through Seaton, we are sceptical that Seaton will be able to perform as an origin and destination hub due to its isolation and distance from major residential and employment centres. While many suburbs are densifying across the GTA, creating a polycentric region, local media reports a refusal by the provincial government to intensify lands north of Pickering, Ontario; striving to protect the local Oak Ridges Moraine, and prevent uncontrolled sprawl (Calis, 2015; Ogilvie, 2010). It is therefore recommended that Metrolinx re-evaluate the potential costs and benefits of adding transit to Seaton, as the current land use and apparently political climate of the area will not likely support major transportation investment.

Case Study 4: Urban Success Mobility Hub: St George

Figure 4.7: St George Mobility Hub Land Use Profile



The St George mobility hub is an excellent example of a successful gateway mobility hub in the GTA. Situated at the intersection of Bloor Street and St. George Street, this hub spans the heart of a dense, mixed use destination. Served by three subway stations in a 1 km radius, and numerous TTC bus and street car lines, this neighborhood promotes high job accessibility, which is only furthered by the adjacent Ontario government complex and commercial storefronts.

With a combination of high-rise condominiums, and low-rise apartments along Bloor Street and St. George Street, the population and job density of the neighborhood are almost unmatched in the GTA. This mixed-use built environment translates into a highly walkable neighborhood, which diverts the need of travellers away from the car.

Finally, the interaction between land use and transportation is directly in tune with the needs of the local population. With a very low average household income, and high proportion of unemployed and migrant residents, this neighborhood is socially deprived. As this tends to increase the likelihood that residents will not only want, but need transit, (Gutiérrez et al., 2011) numerous public transit options provide well for the local community. The results of this study therefore suggest that St George is an ideal mobility hub in the City of Toronto; providing multiple, frequent transit options connecting residents to Union Station, and regional transit. We recommend that the City of Toronto and Metrolinx continue to provide high frequency service along bus and subway lines in the area, and maintain a standard for land use mixture within any new-build developments. This level of service allows for atypical commute patterns out of this neighborhood to use public transit reliably.

Table 4.6: St George Hub Characteristics

Existing Demand	**Value**	**Ranking**
Origin Mode Share	36%	
Destination Mode Share	39%	
Population Characteristics		
Population Density	7900 people/km^2	
Average Income	$41,088.70	
Average Household Size	2.5	
Spending more than 30% of income on housing	4.70%	
Percentage of recent immigrants	19.60%	
Unemployment Rate	13%	
Built Environment Characteristics		
Walk Score	97	
Job Density	9600 jobs/km^2	
Accessible Jobs	197,000 jobs	
Distance to the nearest highway	3.2 km	
Subway Station	Yes	
Transit Characteristics		
Number of Rail Stations	1	
Average Peak Service Frequency	3.5 minutes	
Number of Transit Providers	1	

Updated Toronto "Rocket" Subway, TRAM

5 LOOKING FORWARD

Public transit is becoming increasingly necessary in major cities, especially those battling congested freeways. The residents of Toronto, Ontario are all too familiar with this concept. In a region where local governments are seeking out freeway tolling to desperately dampen congestion (Amborski, 2017), and find transit as an alternative mode. Toronto's regional transit agency, Metrolinx, is responding by proposing 51 mobility hubs that would link residents and jobs across this polycentric city.

Although significant precedent research exists outlining general factors that influence transit use, little precedent has been set proposing quantitative thresholds and policy proposals for improving inbound and outbound transit share. In this study, we develop two models, one predicting outbound transit mode share (origin) and another predicting inbound mode share (destination). Using the results of these models, we assess the origin and destination transit use at all mobility hubs in the Greater Toronto Area (GTA), categorize them, and propose a slate of policy interventions for each hub, targeted at increasing mode share.

We found that origin and destination mode share, as expected, are informed by distinct factors. The results demonstrate that sociodemographic characteristics such as income and employment are relevant to the origin mode share, while built environment characteristics such as walkability and transit service type are more relevant for a destination. Using the results of this model, we created a value for the origin and destination transit demand at each mobility hub in the GTA. It is apparent from the results of this step that not all mobility hubs are created equal, and their label does not carry a consistent meaning. While many mobility hubs are dense, mixed-use, and intermodal areas, others have not yet been touched by planners, and currently lie in a low-density, suburban neighborhood with little or no accessible transit (Metrolinx, 2015). To improve this, we then adjust values within the model one at a time to isolate the impact of policy interventions such as density quotas, or service changes. Using these results, four categories of mobility hubs emerge based on whether improvement should be tailored to home, work, both, or neither. Our findings suggest that built environment characteristics such as service frequency and the addition of a subway station at some hubs will have the largest effect on transit mode share.

For mobility hubs with a weak origin transit mode share, it is imperative to increase the number of morning commute trips made by transit. In order to do this, we propose either (1) a change in the local population density, or (2) a change in job accessibility. It is unreasonable to simply suggest that Metrolinx densify a neighborhood. However, there are several strategies used in precedent hub developments that may be of use. Increasing articulated density, or a preference for high density, high occupancy buildings surrounded by green space, will benefit transit use (Suzuki, H., Cervero, R., Kanako, I., 2013). Similar to the development of transit oriented developments, it is recommended that densification take place at mobility hubs where no transit infrastructure currently exists.

Considering that Metrolinx is currently overhauling many stations, and that Toronto's housing market is densifying quickly, this approach is feasible. In modern economics, however, workplaces tend to relocate much faster than households in response to ideal demand and market conditions (O'Regan & Quigley, 1998). In partnership with municipal and provincial levels of government, capitalizing on available tools such as loosened regulations in certain municipalities, or tax adjustments based on location may be useful. It is important to note that the installation of new, efficient transit lines is also a step towards dense residential and employment centres, as many developers and firms may choose to locate based on local opportunities (Pickrell, 1985).

We also propose three possible interventions for improving destination mode share; (1) improving land use mixture and walkability, (2) increasing service frequency and (3) integrating the hub with a subway line. While Walk Score has been used as a proxy for land use mixture and walkability, it is not realistic to propose that a municipal planning agency strive to simply increase Walk Score. In reality, we advise that land use mixture be adjusted in new build developments to accommodate commercial-residential mixture, and ensure that assorted daily amenities are located within a walkable distance of a mobility hub. Of all interventions proposed in this study, those relevant to transit have the largest impact on mode share based on our models. The increase of service frequency along major corridors is crucial, especially during peak commuting hours (Taylor et al., 2009). While subway lines in Toronto have an impressive service frequency of 2-5 minutes (Toronto Transit Commission, 2017), local bus routes and regional GO transit often operate at 15-30-minute frequency, or greater. The results of this study show that many hubs with peak frequency of 10 minutes or less have higher transit mode share, and therefore it is recommended that high congestion bus and rail corridors are targeted for service increase.

In the Greater Toronto Area, many failing hubs are situated in the far suburbs or exurban neighborhoods, where little regional or local transit currently exists. In comparison to transfer hubs in other cities such as New York and London, which are consistently intermodal terminals, the proposed mobility hub network is riddled with gaps that Metrolinx must consider prior to investing in transit. While policy advisors are correct to improve transit in these neighborhoods, this action alone is unlikely to yield a successful mobility hub; other variables such as land use mixture, density, accessibility, and demographics must also be considered. With a finite pool of funds to go around, it is key that investments be made in the right place, with maximum benefits for commuters.

The results of this study contribute to knowledge of factors affecting transit mode share at origins and destinations, and are of use to any planning authority seeking benchmarks for successful mobility hubs, and a well-connected transit network. Future studies could use a similar methodology to evaluate changes in mode share before and after improvements to mobility hubs to determine the accuracy of demand prediction models. Furthermore, our study did not take customer satisfaction data into account, opening the door for future studies to incorporate service quality and customer perceptions of transit service into demand models. We therefore hope that this research helps transit agencies to understand what is most impactful when improving the use of public transit for those who truly need it. We also hope to contribute to the balance of hubs as both origins and destinations, as a successful hub is a location for live, work, and play (Metrolinx, 2015).

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